5.13 THERMAL CONTROL SYSTEM (TCS)

The AMS-02 Thermal Control System (TCS) is being developed and designed by the AMS experiment team. During nominal operations on ISS, AMS-02 draws up to 2600 watts of power. This power must be dissipated as heat, while maintaining all components within their temperature limits and maintaining the Vacuum Case as cold as possible. The payload also must be able to survive STS environments, handoff between STS and ISS, periods with no power (both during transfer and while berthed on ISS) and peak power excursions (e.g. magnet charging). Passive thermal design options are utilized as much as possible, but more complex thermal control hardware is required for some sub-detector components to assure mission success. TCS specific hardware includes radiators, heaters, thermal blankets, heat pipes, loop heat pipes, optical coatings and a dedicated CO_2 pumped loop system for Tracker cooling. AMS-02 is designed such that passive thermal control is all that is required to sustain the payload safely through extended periods of power loss without hazard.

5.13.1 Radiators

Most of the heat generated by AMS-02 is rejected to space via dedicated radiators (Figure 5.13.1-1). Ram and Wake Main radiators dissipate heat from numerous electronics crates. Ram and Wake Tracker radiators reject the heat generated inside the Tracker. A zenith radiator rejects heat from the Cryocoolers.

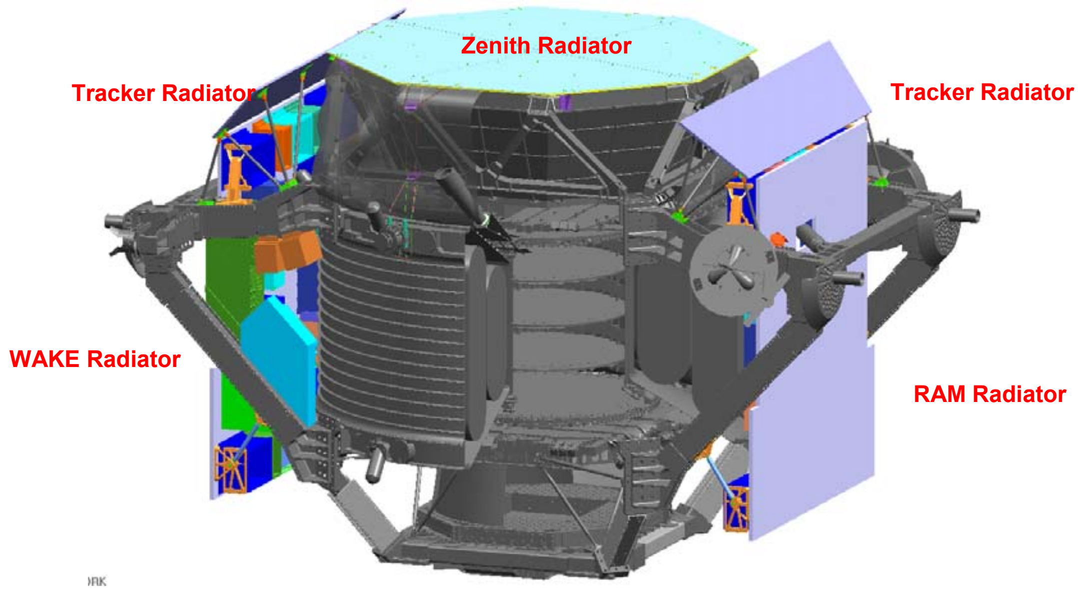


Figure 5.13.1-1 AMS-02 Radiators

5.13.1.1 Main (Electronics Crate) Radiators

The Ram and Wake Main Radiators are designed to both dissipate heat from the electronics crates and provide their structural support. The crates, which are optimized to transfer heat to the radiator, are bolted directly to the honeycomb panel using inserts. A silicone based thermal interface filler, Chotherm 1671, is used to minimize the thermal resistance across this interface. During nominal operations the Ram radiator dissipates 525 watts over its 4.24 m^2 surface area, while the Wake dissipates up to 812 watts over its 3.99 m^2 area. Heaters mounted on these radiators are used to bring electronics above their minimum turn-on temperature after periods without power. The outer surfaces of the radiator face sheets are painted with SG121FD white paint to optimize heat rejection. Portions of the crates and inner radiator surfaces are covered with MLI blankets to minimize heat rejection back to the vacuum case and to adjacent ISS payloads.

These radiators consist of a 25mm thick ROHACELL® core with 0.5mm thick 6061-T6 aluminum face sheets and imbedded heat pipes. A cross section is shown in Figure 5.13.1.1-1. Heat pipe layout are shown in Figures 5.13.1.1-2 a and b. The heat pipes are standard axial groove, made of aluminum 6063 and filled with high purity ammonia.

Each Main Radiator mounts to the USS-02 at six locations. Two brackets at the top fix the radiator to the Upper Trunnion Bridge Beams; two mid-brackets fix the middle portion of the radiator to the Lower Trunnion Bridge Beams and two pin-ended struts span the distance from the lower row of crates on the radiator to the Lower Vacuum Case Joint (Figure 5.13.1.1-3).

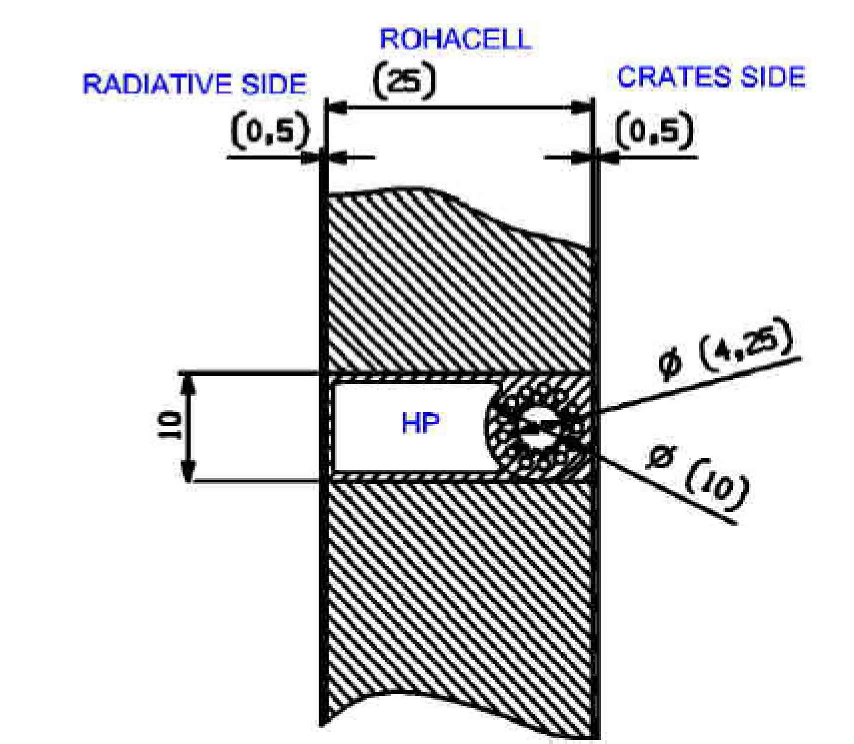
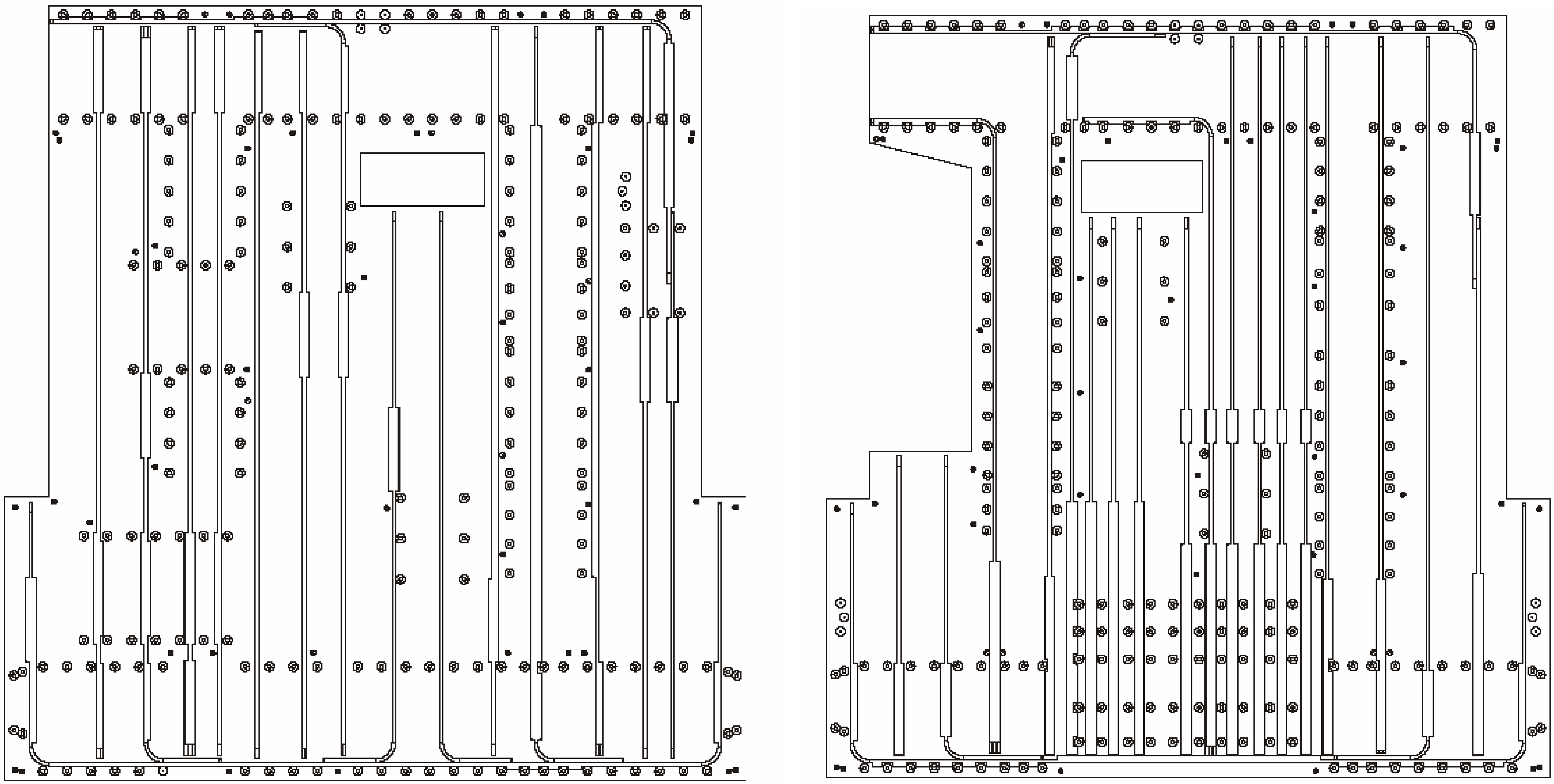


Figure 5.13.1.1-1 Main Radiator Cross Section



a) Ram Main Radiator Heat Pipes

b) Wake Main Radiator Heat Pipes

Figure 5.13.1.1-1 Ram and Wake Main radiator Heat Pipe Layout

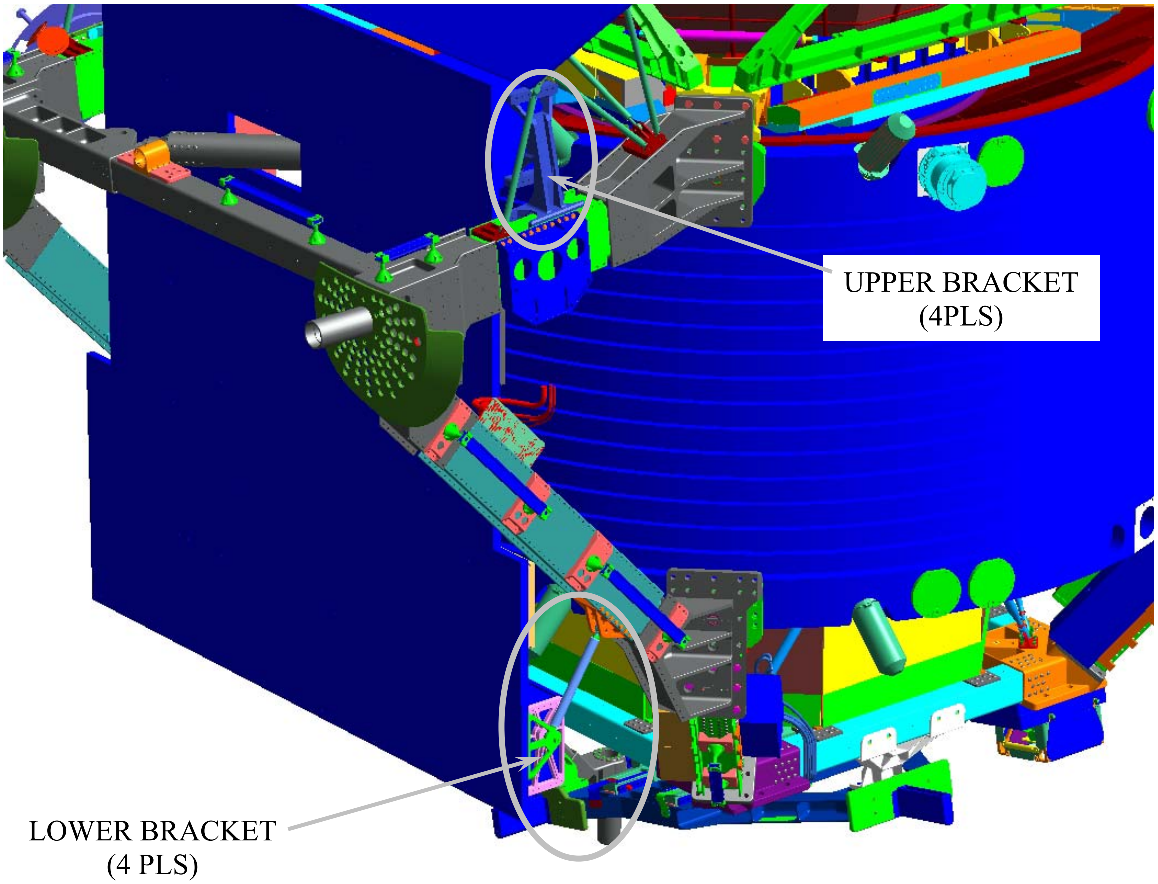


Figure 5.13.1.1-3 Main Radiator Attachment to USS-02

5.13.1.2 Tracker Radiators

The Ram and Wake Tracker radiators are designed to reject the heat transported by the Tracker Thermal Control System (TTCS), a two-phase CO_2 loop running from inside the Tracker (~144 watts) to condensers mounted on the Radiators (Figures 5.13.1.2-1 and 5.13.1.2-2). This CO_2 cooling loop is discussed in more detail in Section 5.13.6. Tracker radiators use Aluminum 2024 T81 face sheets with a ROHACELL® 52 core and imbedded aluminum/ammonia heat-pipes (Figure 5.13.1.2-3). The tracker radiators are trapezoidal, with a lower width of 2250 mm, an upper width of 2500 mm, and a height of 530 mm. 7 heat pipes are embedded in each Tracker Radiator (Figure 5.13.1.2-4). CO_2 loop condensers mount directly to the heat pipes by bolting through the radiator (Figure 5.13.1.2-5). Each radiator is mounted using 8 pin-ended struts; 1 attached to each of the Upper Trunnion Bridge Beams and 3 attached to each of the Upper Vacuum Case joint (Figure 5.13.1.2-2). There is also a bracket attaching each Tracker Radiator to the adjoining Main Radiator. The outer surfaces of the Tracker Radiators are painted with SG121FD white paint. The back sides will be covered with MLI blankets.

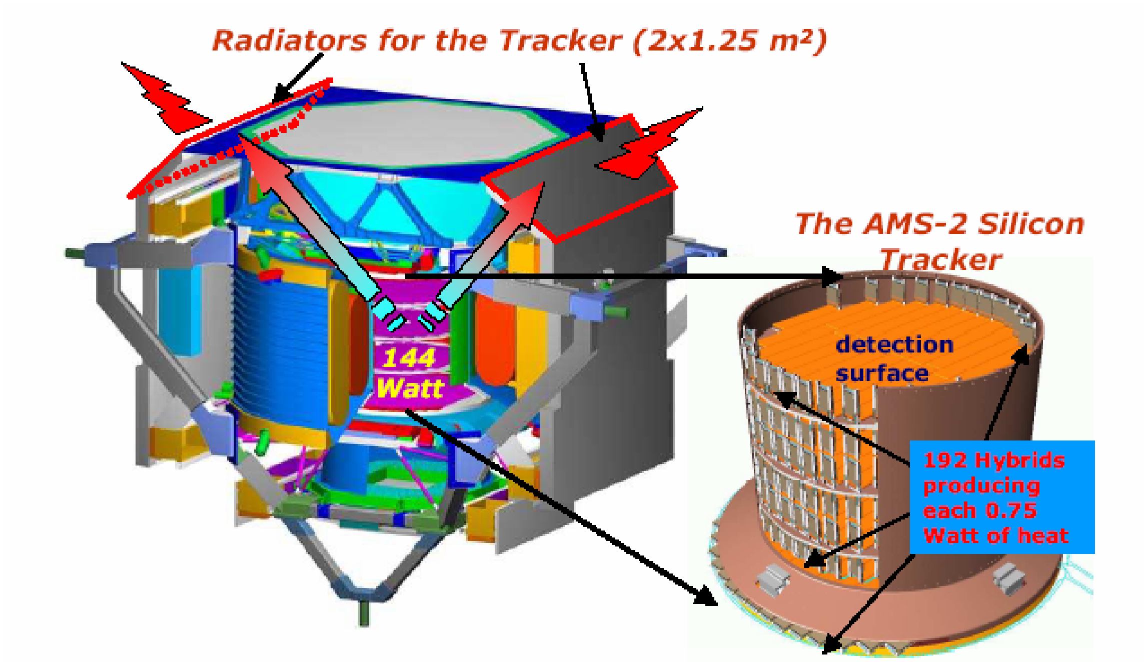


Figure 5.13.1.2-1 Tracker Cooling

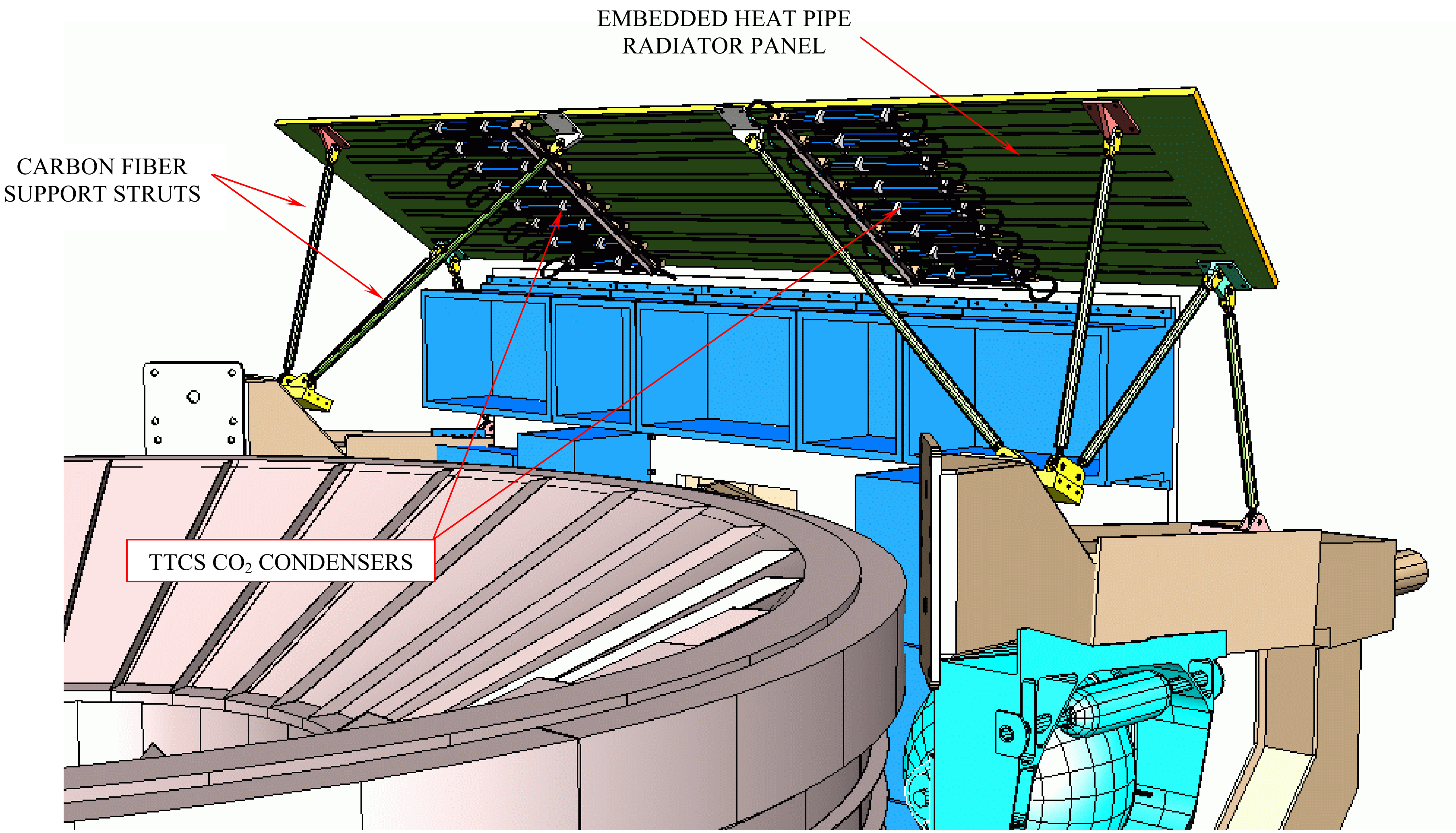


Figure 5.13.1.2-2 Tracker Radiator with TTCS Condensers Mounted
(This picture is outdated – needs to be replaced with one showing the new condenser)

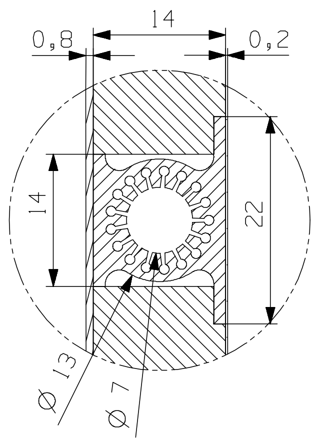


Figure 5.13.1.2-3 Tracker Radiator Cross Section

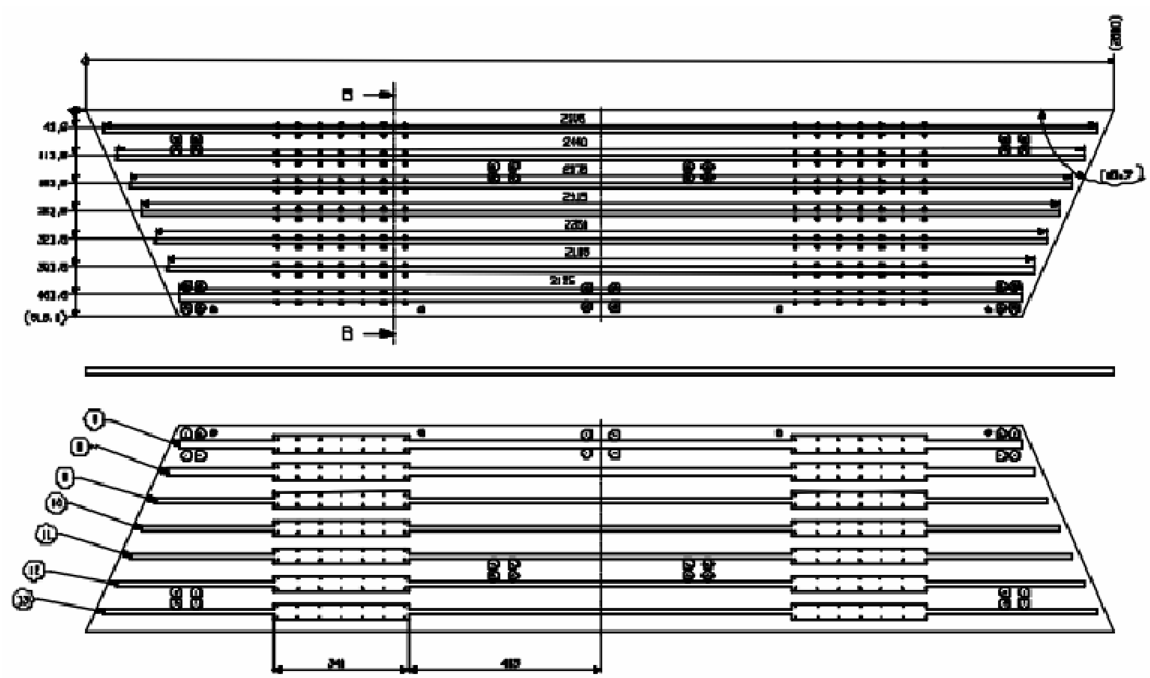


Figure 5.13.1.2-4 Tracker Radiator HP Layout

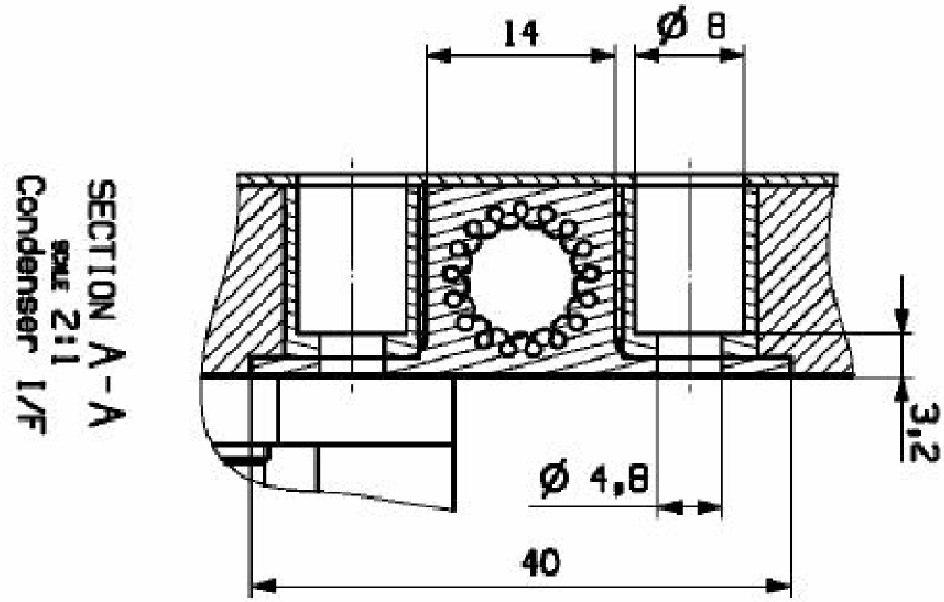


Figure 5.13.1.2-5 TTCS Condenser Mounting

5.13.1.3 Zenith Radiator

The Zenith Radiator actually consists of four separate panels, each design to reject heat (up to 150 watts) transported via two Loop Heat Pipes (LHPs) from a single Cryocooler (Figures 5.13.1.3-1 and 5.13.1.3-2). The radiator panels are constructed with aluminum 2024 T81 face sheets (1.6 mm for the upper face sheet and 0.3 for the lower), with a 10 mm ROHACELL® core (Figure 5.13.1.3-3). The condenser portion of each Loop Heat Pipes is a 4mm OD (3mm ID) aluminum 6063 tube, which is brazed to the upper face sheet of the radiator along a path designed to optimally reject heat. At the outer edge of each panel, the aluminum condenser tubes transition to stainless steel tubes via bimetallic joints. Each radiators panel is mounted to the top of the Upper TRD honeycomb panel via 14, 3mm OD x 35 mm long carbon-fiber pins, design to minimize heat leak, and two brackets; a Glass Fiber Reinforced Polymer (GFRP) bracket in the center and an aluminum one on the outer edge (Figure 5.13.1.3-4). The outer face of the Zenith Radiator is covered with Silver-Teflon film to maximize heat rejection capability. An MLI blanket is used on the under side to isolate the Zenith Radiator from the TRD.

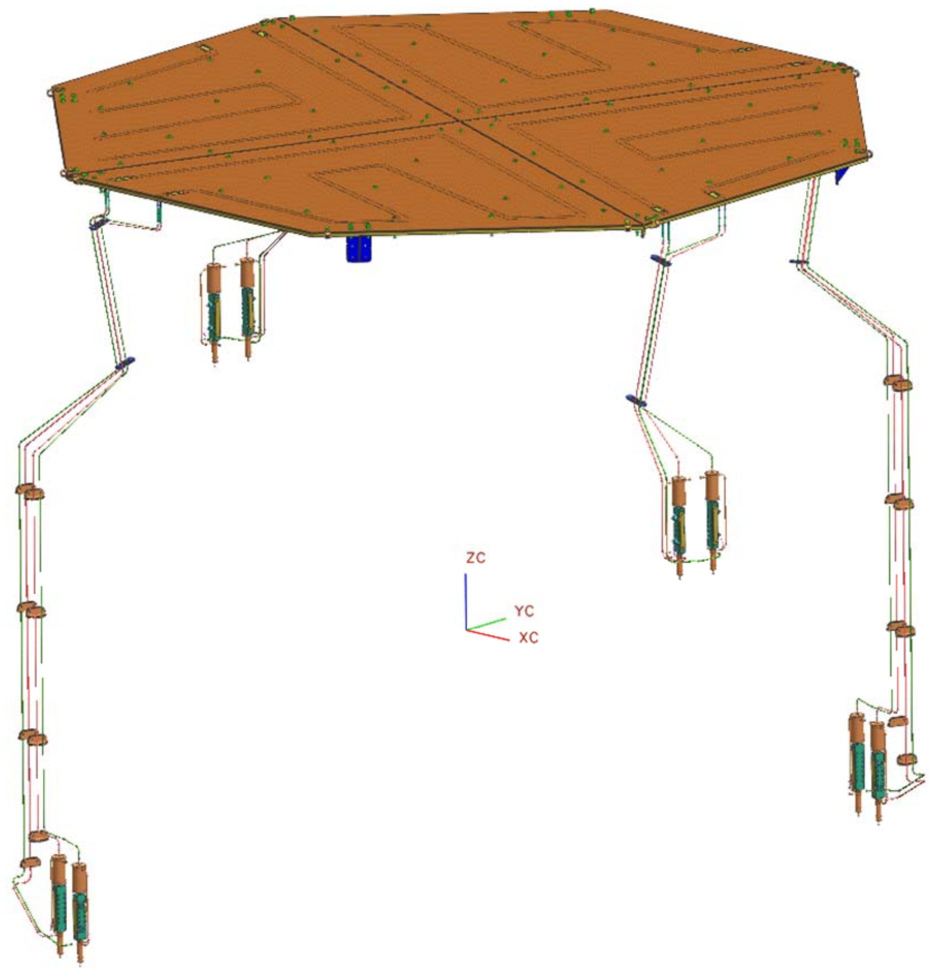


Figure 5.13.1.3-1 Zenith Radiator Panels

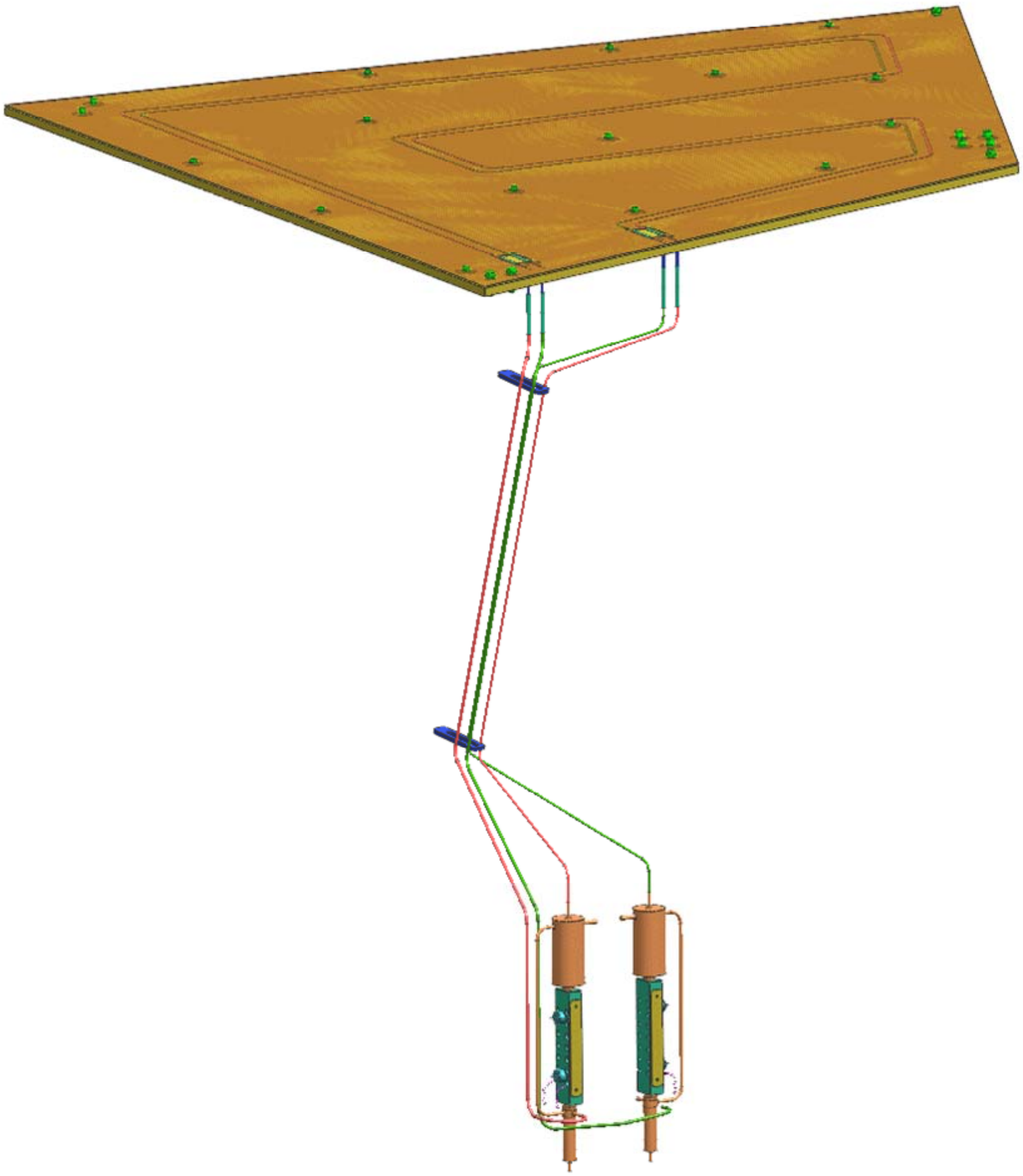


Figure 5.13.1.3-2 Zenith Radiator Panel with LHP

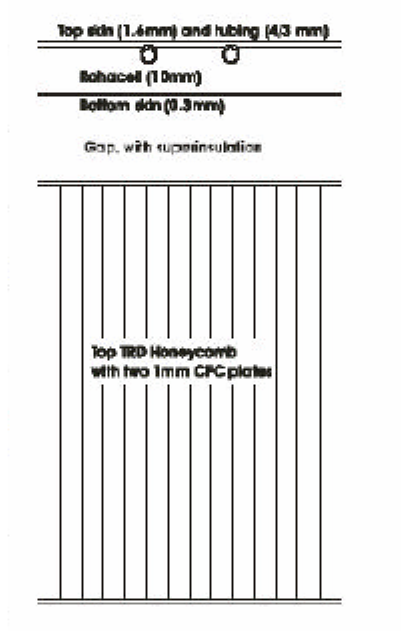


Figure 5.13.1.3-3 Zenith Radiator and Upper Honeycomb Panel Cross Section showing the gap between the radiator panel and the TRD upper honeycomb panel

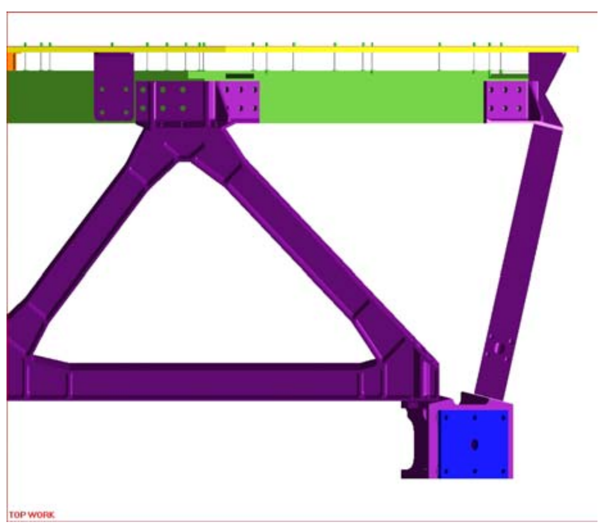


Figure 5.13.1.3-4 Zenith Radiator Mounting

5.13.2 Multi-Layer Insulation (MLI) Blankets

AMS-02 will have numerous MLI blankets on various components and sub-detectors. Concepts for a few of the larger blankets are shown in Figure 5.13.2-1. Typical construction will include Beta cloth as the outermost surface, 5 to 20 layer of aluminized Mylar separated by Dacron scrim, and reinforced aluminized Kapton as an inner surface. All MLI blankets used on AMS-02 will meet or exceed the NASA requirements for grounding and venting and will be positively secured. These requirements are called out in CTSD-SH-1782, Multi-Layer Insulation for the Alpha Magnetic Spectrometer Guidelines Document.

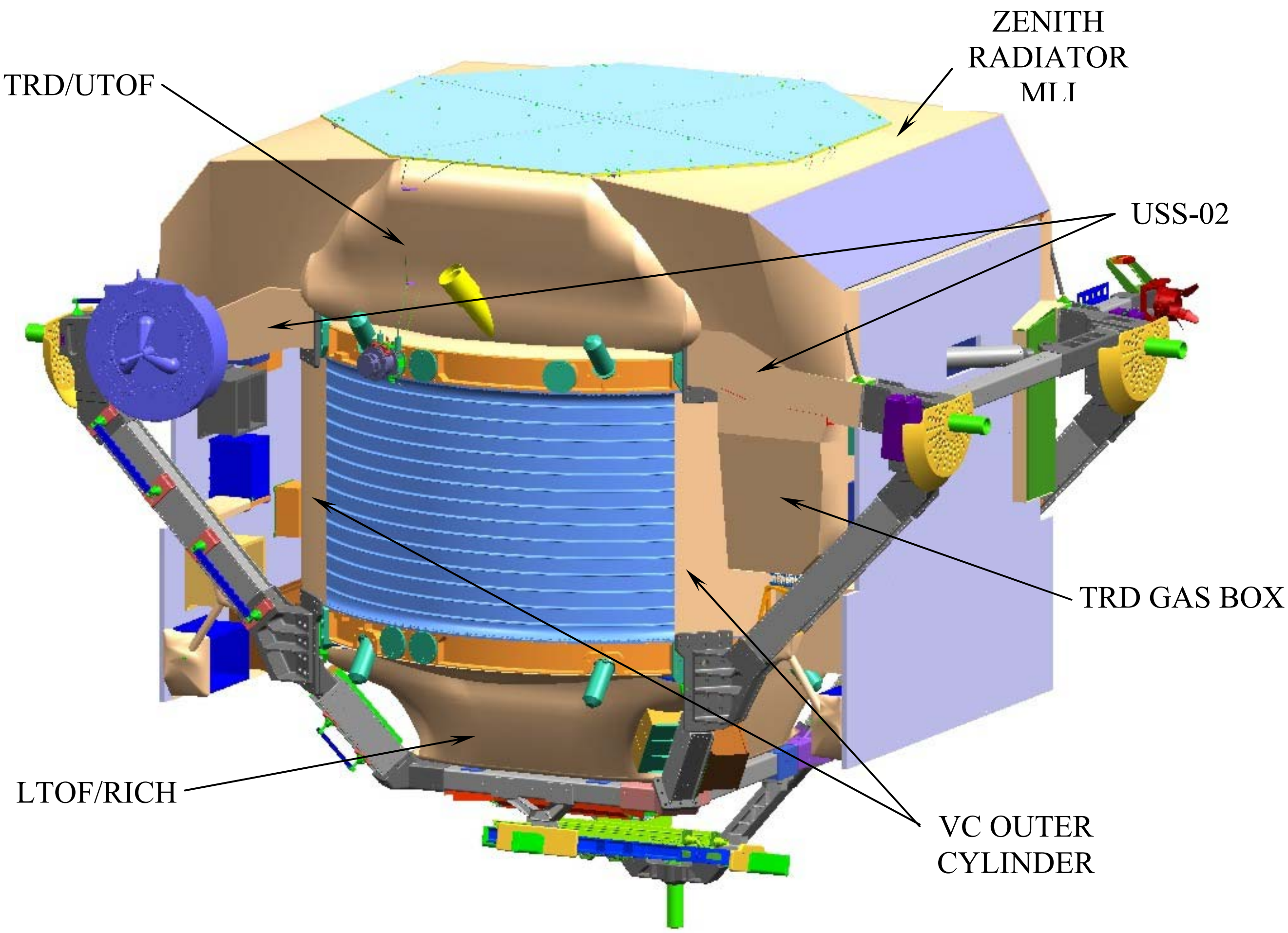


Figure 5.13.2-1 AMS-02 MLI Blankets

5.13.3 Heaters

Most heaters on AMS-02 will be used to assure that electronics are sufficiently warm before they are turned on. These heaters are mounted on the Main Radiators at locations where the embedded heat pipes can conduct heat to the crates. When AMS-02 first receives power, thermostatically controlled heaters warm up the Power Distribution System (PDS) crate to its minimum switch-on temperature. After the PDS is turned on, it then enables other heaters to warm up other electronics. When switch-on temperatures are achieved, heaters are disabled (by the PDS) prior to turning on electronics. The PDS provides 11 distinct 120V heater circuits which may be disabled or enabled as needed. A more detailed discussion of this system and the start-up procedure is found in Section 6.0, AMS Flight Operations Scenario.

Additional heaters that will be activated during normal operation include those for the RICH, ECAL, Lower TOF, TRD, TRD Gas System, Tracker Thermal Control System, CAB, High Voltage Bricks, and possibly for the Warm Helium Supply. Heaters on the TTCS CO_2 lines will be used to thaw frozen CO_2 in the event of a loss of power while in a cold environment (see Section 5.13.6.3). Heaters on the Cryocoolers are used to heat then up to their minimum switch-on temperature and to start the Loop Heat Pipes.

Analysis will be performed to evaluate the effects of "run away" heaters. Heaters will be sized based on the minimum expected voltage, but failure analysis will be performed at the maximum voltage. Appendix B provides details for all heaters used on AMS-02.

5.13.4 Heat Pipes

Passive thermal control of AMS-02 includes the use of various axial groove heat pipes. These "standard" heat pipes are not to be confused with the Loop Heat Pipes discussed in Sections 5.13.5 and 5.13.7. While AMS-02 heat pipes vary in terms of length and cross section, all are constructed of aluminum and filled with high-purity ammonia. The amount of ammonia in each pipe is so small that freezing poses no concern.

As discussed in Section 5.13.1, heat pipes are embedded in both the Tracker and Main Radiators to help distribute heat. Besides radiators, heat pipes are also used in the Cryomagnet Avionics Box (CAB) base plate (Section 5.13.7), the TTCS control box (Section 5.13.6) and to minimize temperature gradients across one of the USS-02 joints (Section 5.13.7).

5.13.5 Optics

Thermal optical properties of external AMS-02 surfaces play a critical role in the thermal control of the payload. Typically surface optical properties are selected to bias temperatures cold where needed. This is achieved by selecting coatings which have a low ratio of solar absorptivity (α) over Infra-Red (IR) emissivity (ε)

Much of AMS-02 is covered with MLI blankets, which use a glass-fiber cloth (e.g. Betacloth) as the outer surface. The Main Radiators and Tracker Radiators are painted with SG121FD white paint, a very stable, low α / ε coating similar to what is used on the ISS radiators. The Zenith radiator, +/- X quadrants of the Vacuum case, portions of the USS-02, +Y face of the CAB, and various other small electronics are covered with a silver-Teflon film (typically 5 or 10 mil FEP over vapor deposited silver over vapor deposited Inconel with 966 acrylic adhesive). This film has the lowest ratio of α / ε, but since it is highly specular, its use is limited to surfaces where it is absolutely needed. All exposed aluminum surfaces are anodized for corrosion protection. Except for a few exceptions (handrails, grapple fixtures) this is a clear anodize which keeps temperatures reasonably cool. Table 5.13.5-1 lists optical coatings and properties for all significant exposed surfaces (bolt heads, rivets, cable ties, etc. are not considered thermally significant).

TABLE 5.13.5-1 AMS-02 SURFACE OPTICAL PROPERTIES

Surface Optical Property	Beginning of Life (BOL)		End of Life (EOL)	
	Absorptivity (α)	Emissivity (ε)	Absorptivity (α)	Emissivity (ε)
Beta Cloth	0.22	0.9	0.47	0.86
White paint (SG 121)	0.18	0.94	0.27	0.88
aluminized polyimide	0.14	0.05	0.14	0.05
Silver Teflon 5mil	0.08	0.78	0.13	0.75
Silver Teflon 10mil	0.09	0.89	0.15	0.85
Mixed properties (on Magnet)	0.16	0.80	0.32	0.77
anodized aluminum (clear anodize)	0.35	0.84	0.77	0.81
RICH Mirror	0.03	0.82	0.10	0.75
black anodized	0.88	0.82	0.88	0.78
gold anodized AL	0.59	0.84	0.68	0.84

5.13.6 Cryocooler Cooling

Cryocooler cooling is achieved using two redundant propylene Loop Heat Pipes (LHPs) to collect and transport heat from each of the four cryocoolers to a zenith-mounted, direct-flow radiator (Figure 5.13.6-1). The Loop Heat Pipes (along with the Zenith Radiators) are being built by TAIS/Moscow and are similar to those successfully demonstrated as part of the Combined Two Phase Loop Experiment (COM2PLEX) flown on STS-107. The evaporator portion of each LHP is attached to a heat rejection collar on the cryocooler body (Figure 5.13.6-2). This bolted interface includes an Indium interface filler to minimize the thermal resistance. The LHP does not interface directly with the Cryomagnet pressurized systems.

Heaters are used for Cryocooler startup and to keep them above minimum storage limits (Figure 5.13.6-3). A control valve is used to redirect flow into a bypass loop if cryocooler temperatures start getting too cold (Figure 5.13.6-4). This valve uses a bellows system, filled with Argon at a predetermined pressure to control the direction of propylene flow (Figure 5.13.6-5). Each LHP is made primarily of stainless steel, with nickel wicks and high purity propylene as a working fluid. 3 mm stainless steel tubing runs to the edge of the radiator, where it is transitioned to aluminum tubing via a bi-metallic joint. As mention in the previous section, this aluminum tubing is brazed to the upper aluminum skin of the zenith radiators.

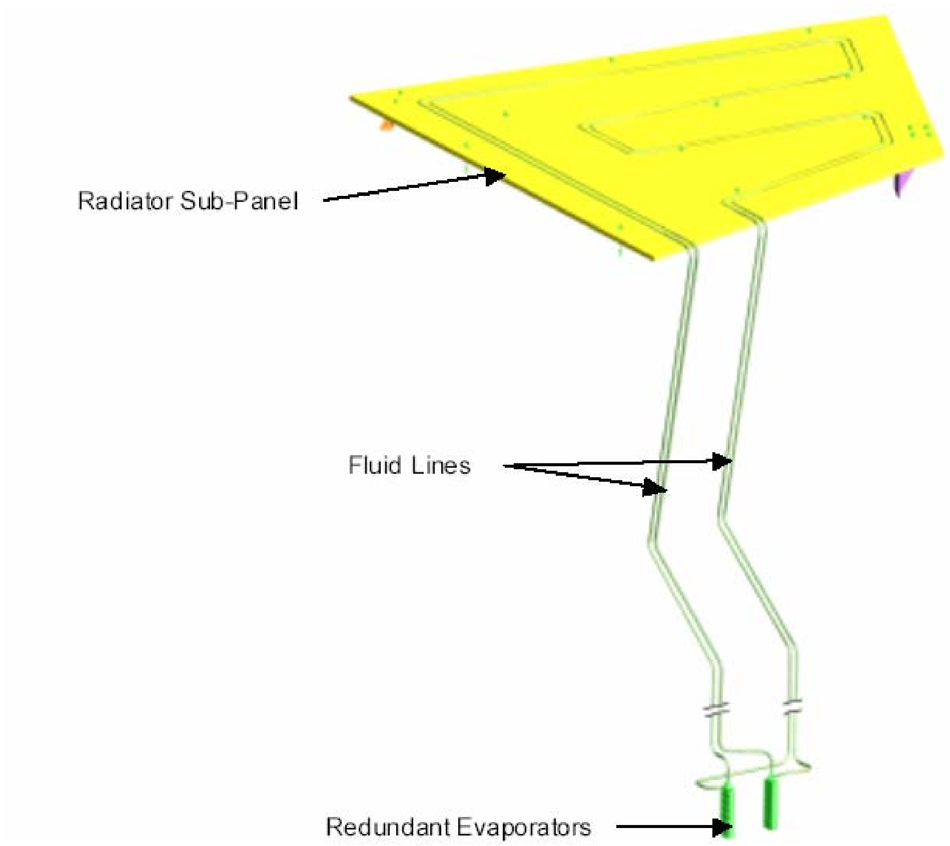


Figure 5.13.6-1 Zenith Radiator Panel with LHP

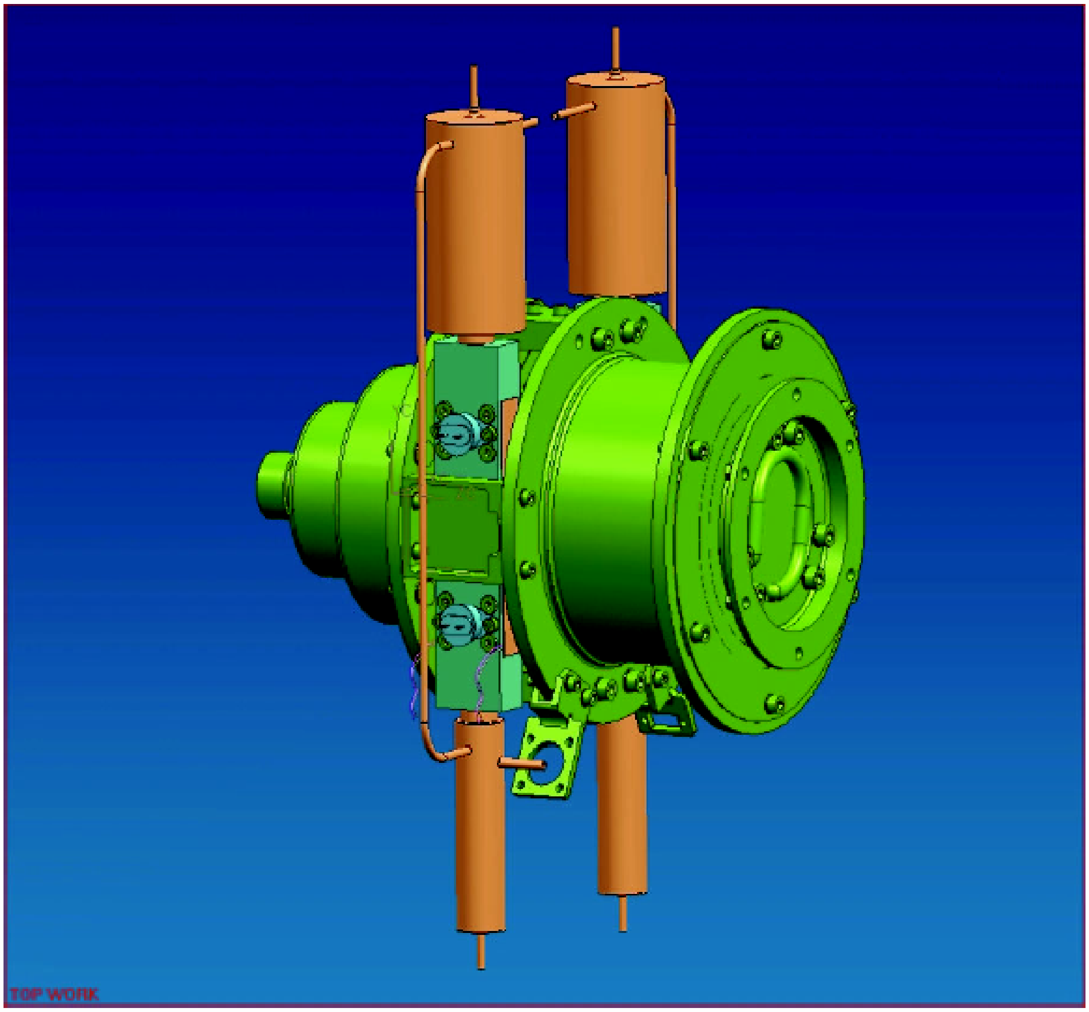


Figure 5.13.6-2 LHP Evaporators Mounted on Cryocooler

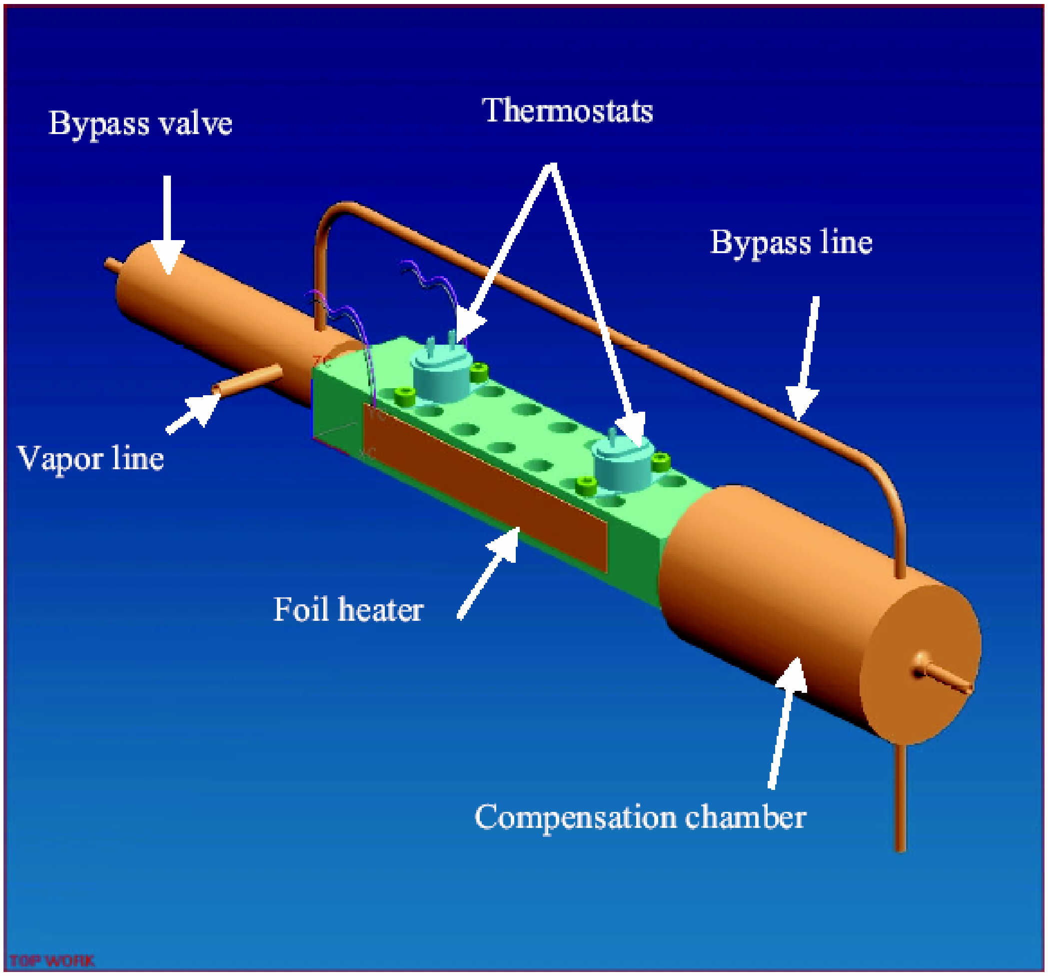


Figure 5.13.6-3 LHP with Bypass

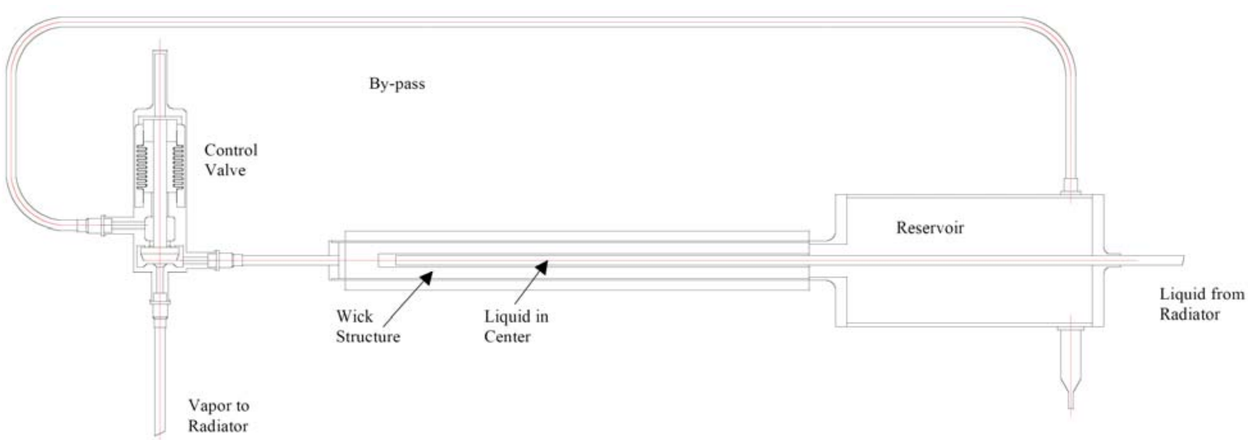


Figure 5.13.6-4 Schematic of LHP with Bypass

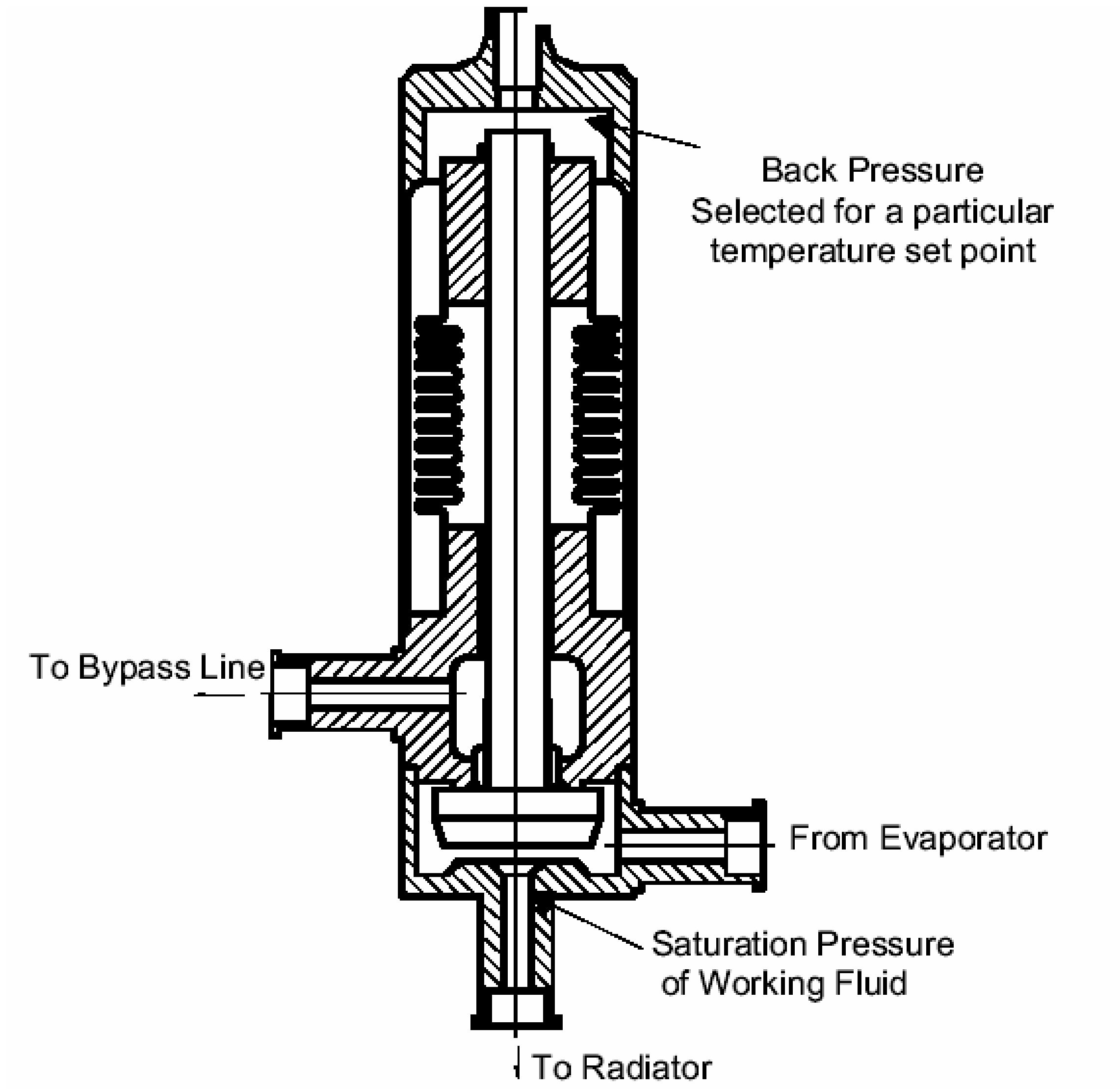


Figure 5.13.6-5 LHP Bypass Valve Cross Section

5.13.7 Tracker Thermal Control System (TTCS)

The TTCS is one of the most complex thermal control systems used on AMS-02 (Figure 5.13.7-1). The Tracker, completely encased inside the inner bore of the Vacuum Case, generates 144 watts which need to be rejected while minimizing heat flow to the vacuum case inner cylinder. The TTCS thermal design includes thermal bars, a pumped CO_2 cooling loop, radiators, manifolds, accumulators and numerous other components.

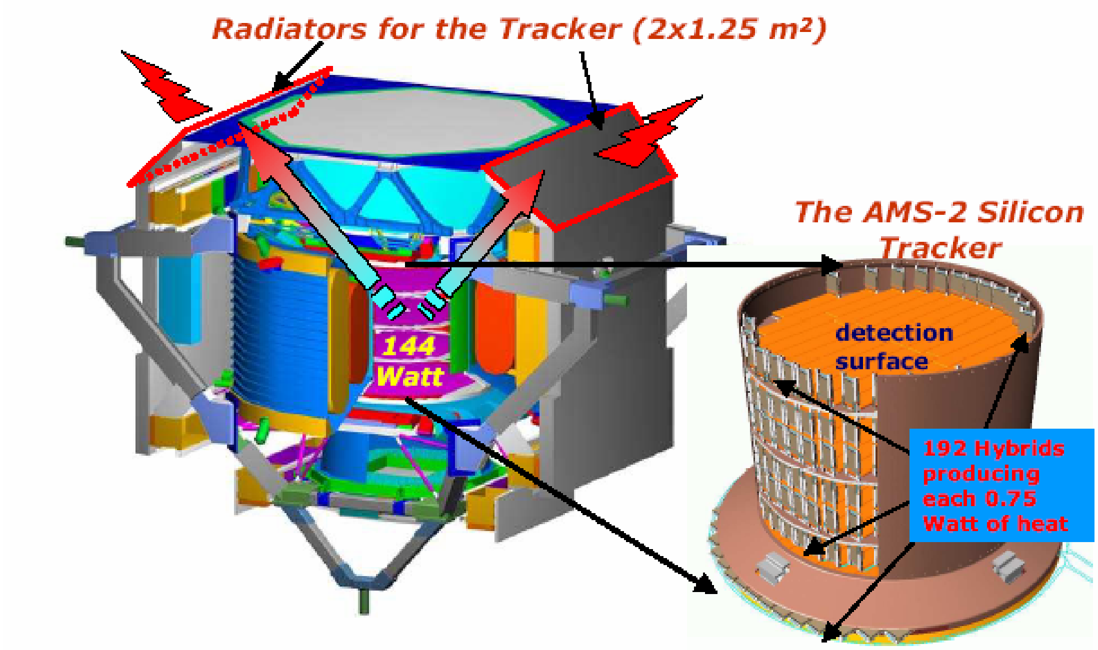


Figure 5.13.7-1 TTCS System

5.13.7.1 TTCS Evaporator

Each of the 192 hybrid electronic boards or Hybrids, located on the periphery of 8 Tracker planes, generates 0.75 watts (Figure 5.13.7.1-1). There are 6 inner rings of Hybrids inside the Vacuum Case Inner Cylinder, 1 above and 1 below. The Hybrids are attached to thermal bars, frames made of Thermal Pyrolytic Graphite (TPG) encased in aluminum 6061 (Figure 5.13.7.1-3). Between inner planes, the Thermal Bars are thermally connected to each other via flexible connecters made of copper. Thermal

Bridges, also made of copper, connect the end thermal bars to the inner evaporator ring tubes (Figure 5.13.7.1-4). Hybrids on the two Outer Planes connect to the outer ring evaporator tubes via copper braids (Figure 5.13.7.1-5). There is an Inner and Outer ring evaporator on both the upper and lower Tracker flange (Figure 5.13.7.1-6). For redundancy, all evaporators include two separate tubes connected to independent cooling loops.

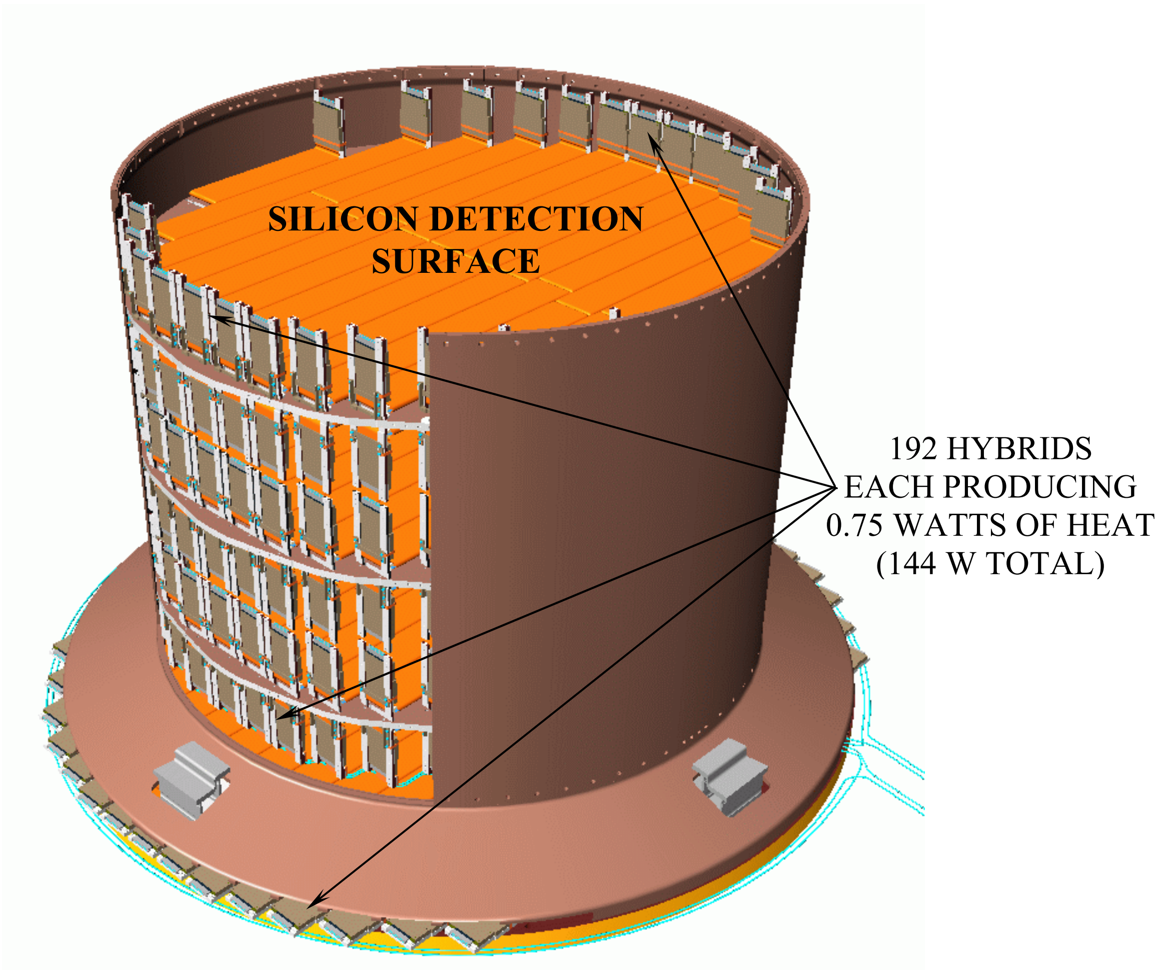


Figure 5.13.7.1-1 Tracker Hybrids

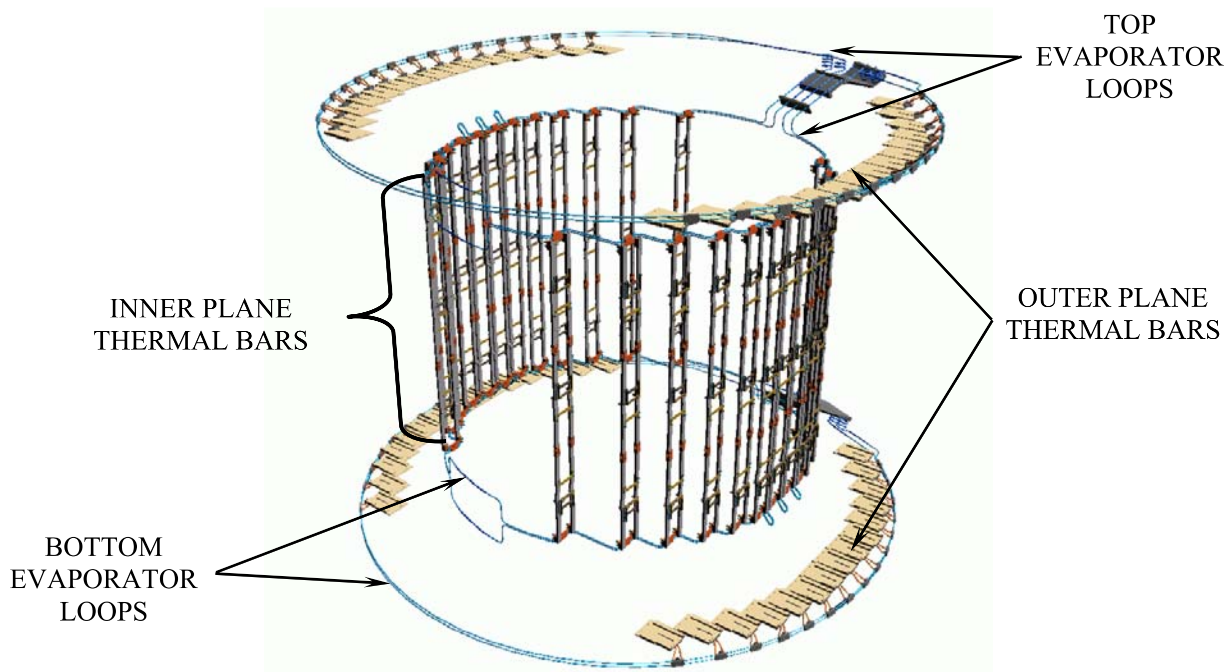


Figure 5.13.7.1-2 TTCS Evaporator

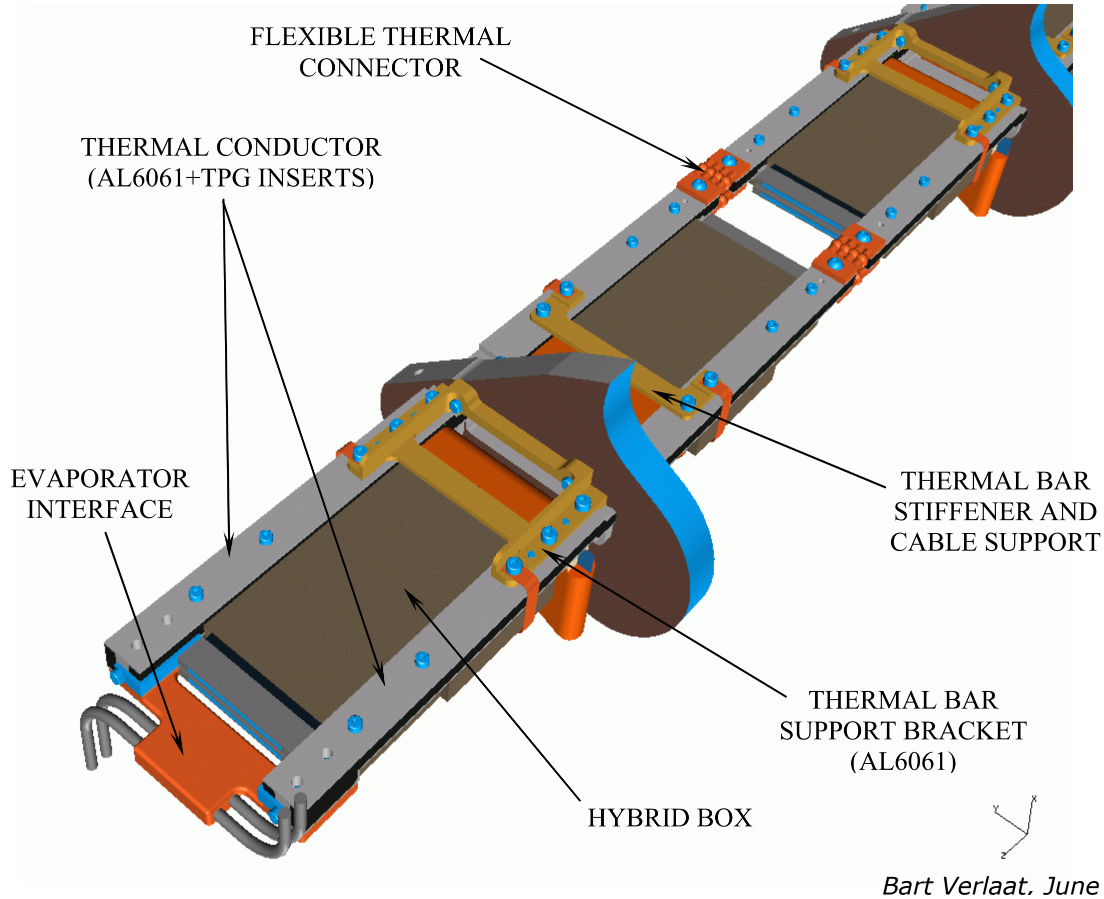


Figure 5.13.7.1-3 Internal Thermal Bar design for AMS-02

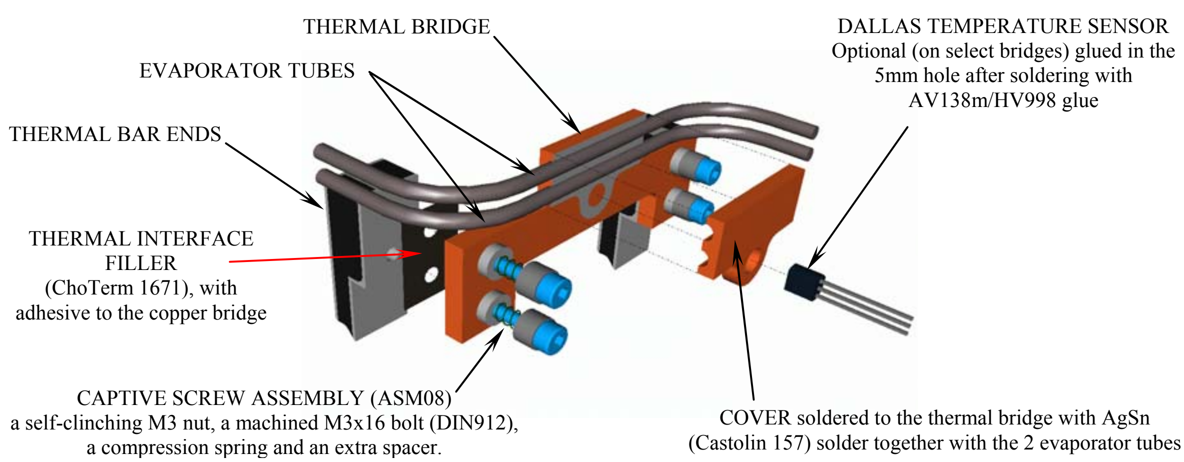


Figure 5.13.7.1-4 Connection between End of Thermal Bars and Inner Evaporator

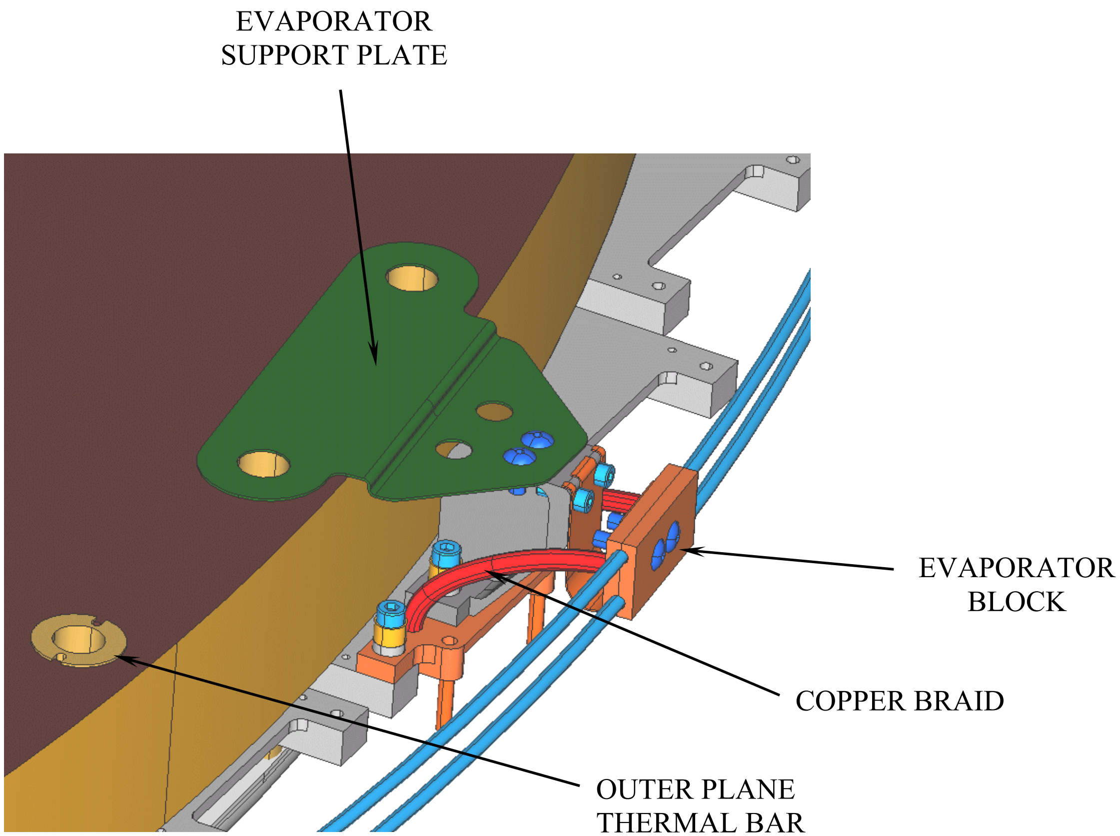


Figure 5.13.7.1-5 Connection between Outer Plane Thermal Bars and Evaporator

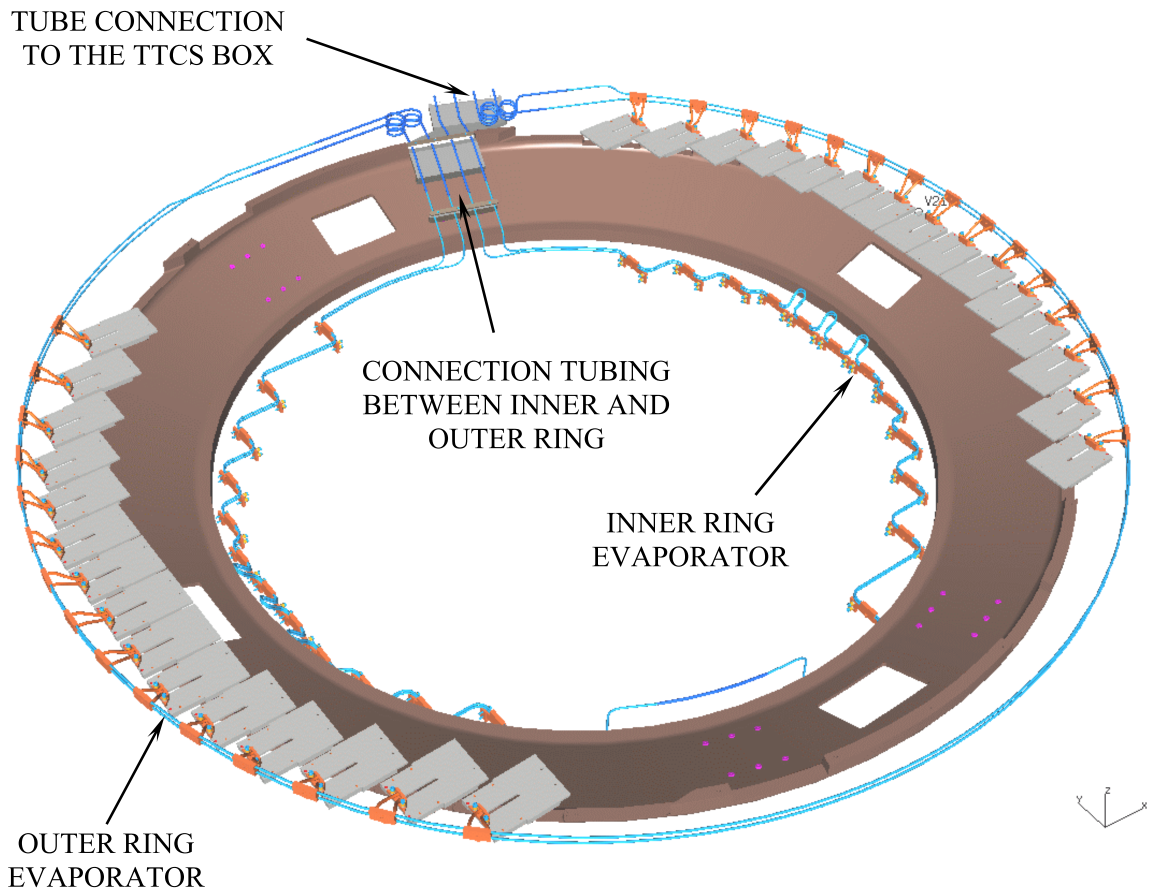


Figure 5.13.7.1-6 TTCS Evaporators

5.13.7.2 TTCS CO_2 Cooling Loop

The TTCS cooling loop uses carbon dioxide to pick up heat from the evaporator rings inside the Tracker. The CO_2 transports heat to condensers connected to radiators on both ram and wake sides of AMS. Fluid is transported back to the evaporator by means of a mechanical pump. Condensers and radiators are designed to assure that the CO_2 is sufficiently cooled so that only liquid will enter the pump.

To maintain the Tracker as isothermal as possible, two-phase cooling is desired throughout the evaporator. This is achieved by using an electric heater to pre-heat the fluid to the saturation temperature before it enters the evaporator. To minimize required heater power, a heat exchanger connects the evaporator inlet and outlet near the electric pre-heater. Figures 5.13.7.2-1 and 5.13.7.2-2 show schematics of the Primary and Secondary TTCS Cooling Loops. The loops are identical except that the Primary Loop includes a small independent experiment, an Oscillating Heat Pipe (OHP), which will be described later, and a section with four valves to force flow to an accidentally blocked condenser. (NOTE: This section will be removed from the design if testing of the engineering model shows no anomalies.)

For each loop, the accumulator, heat exchanger, pre-heaters and cold-orbit heater are located in the Tracker Thermal Control Box (TTCB) as shown in Figure 5.13.7.2-3. The pump and the valves are located next to the TTCB in a separate compartment on a radiator plate also shown on Figure 5.13.7.2-3. The Oscillating Heat Pipe is also located in the Primary TTCB. The Primary TTCB is mounted on the +X +Y Lower Trunnion Bridge Beam while the Secondary is mounted to the –X +Y Lower Trunnion Bridge Beam. The boxes are thermally isolated from the beams and covered with an MLI blanket, except for the Wake facing surface which is used as a radiator.

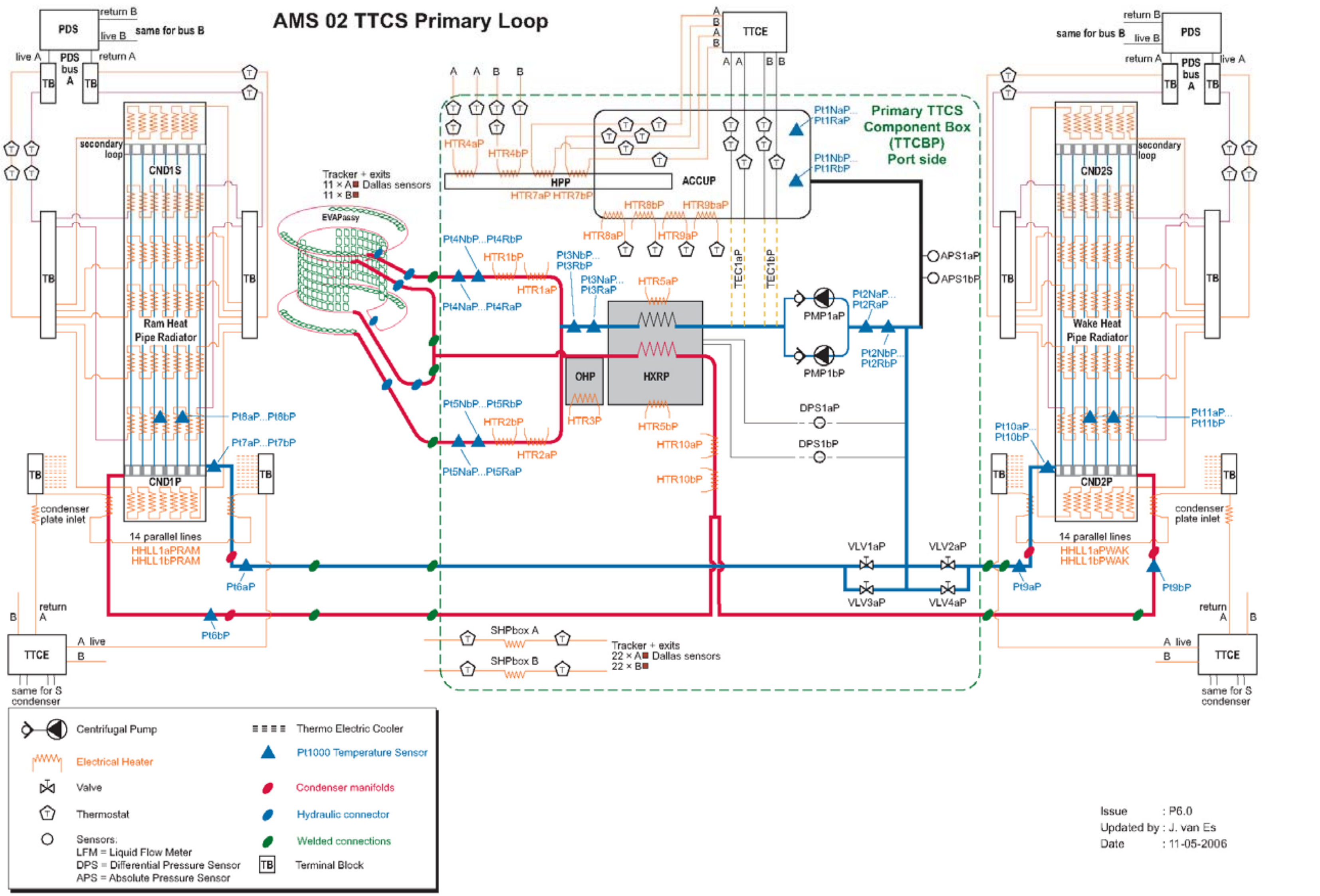


Figure 5.13.7.2-1 AMS-02 Tracker Thermal Control System Primary Loop

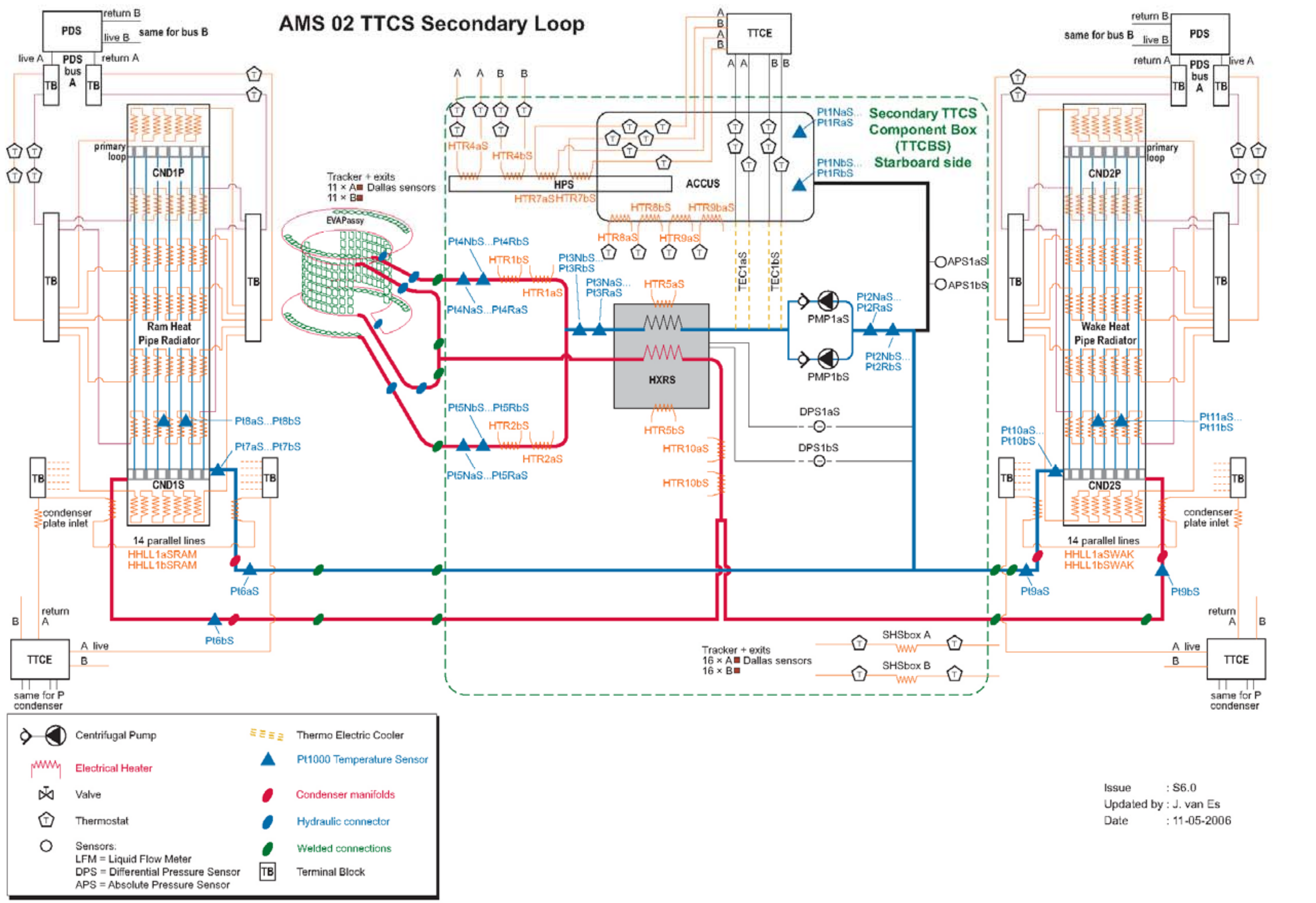


Figure 5.13.7.2-2 AMS-02 Tracker Thermal Control System Secondary Loop

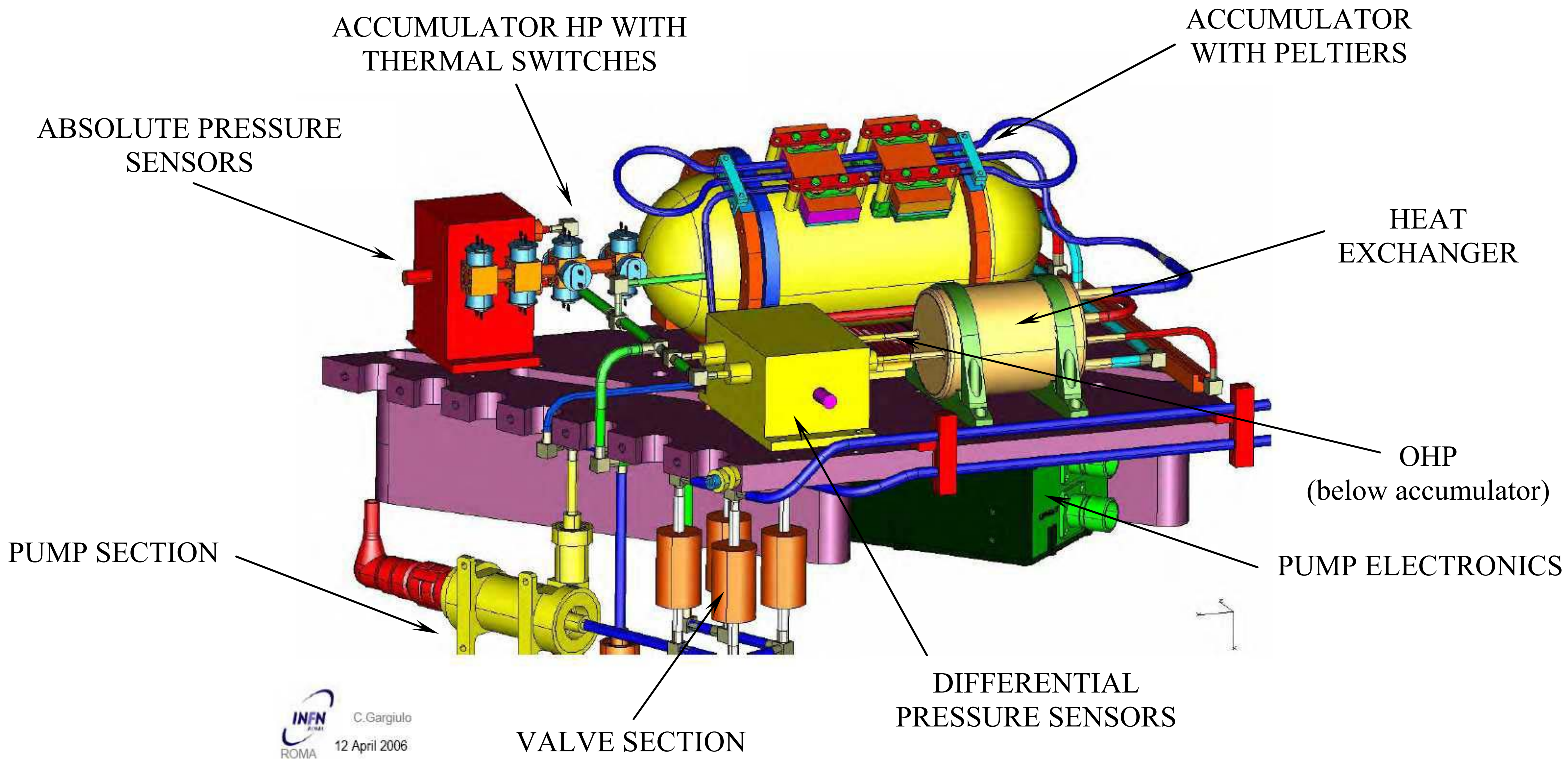


Figure 5.13.7.2-3 TTCB

5.13.7.2.1 Condensers

There are 14 TTCS condensers mounted on both the Ram and Wake Tracker Radiators (Figure 5.13.7.2.1-1). Pairs of condensers are thermally connected to each of the 7 heat pipes embedded in each radiator. Mounting is achieved by bolting through the radiator with Chotherm 1671 used as a thermal interface filler (Figure 5.13.7.2.1-2).

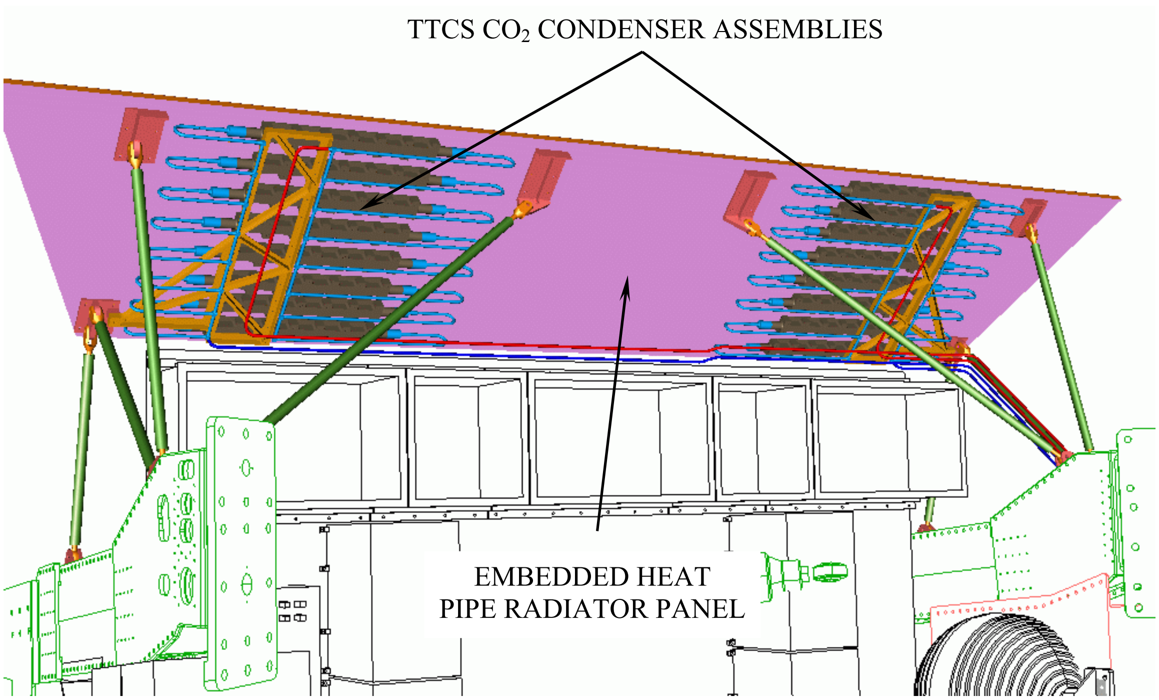


Figure 5.13.7.2.1-1 TTCS Condensers

(This figure is out of date and needs to be replaced. The 16 individual condensers shown here need to be replaced with two of the condensers shown in Figure 5.13.7.2.1-2)

Each condenser is constructed with 7 parallel lines of capillary tubing made of Inconel 718, soldered to an aluminum plate (Figure 5.13.7.2.1-2). Inconel tubing (1mm ID) also runs from the condensers to manifolds mounted on the Vacuum Case conical flange. The manifold combines the parallel flow from the 49 (7 X 7) capillary tubes and transitions it to 2.6 mm ID stainless steel tube. The condensers (including all capillary tubes) are designed to withstand freezing and thaw of CO_2. Heater wires are mounted on the capillary tubes to thaw the lines in case of freezing after loss of power.

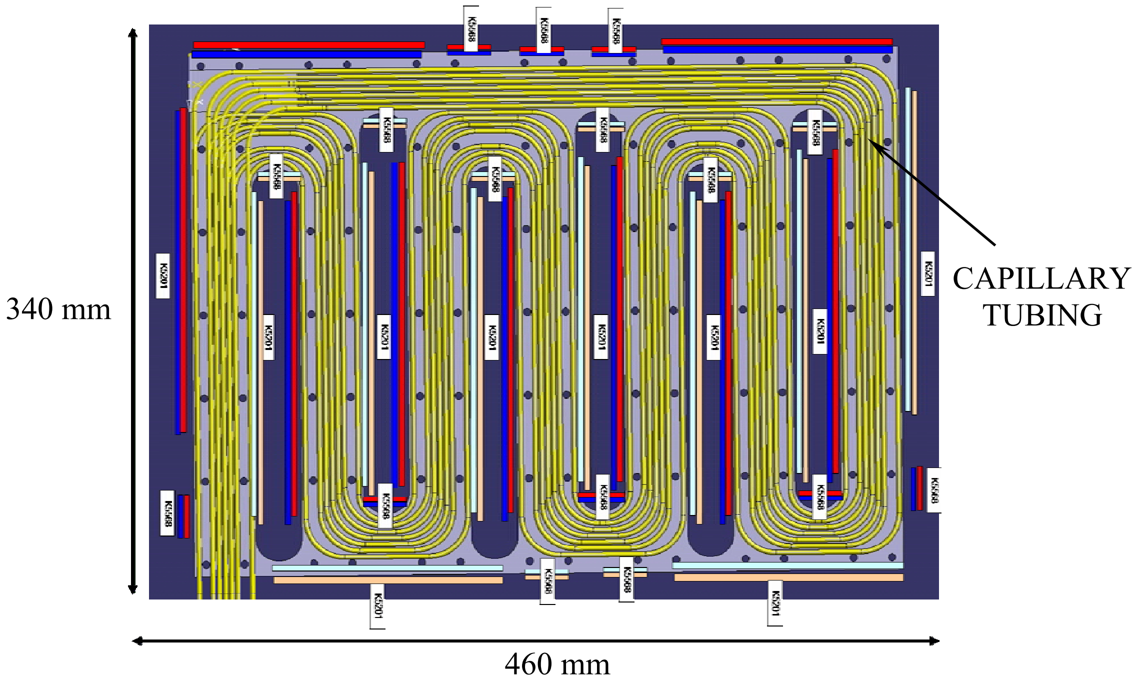


Figure 5.13.7.2.1-2 TTCS Condenser

5.13.7.2.2 Pump

There are a total of 4 TTCS pumps; two for each redundant loop. The single stage centrifugal pumps are provided by Pacific Design Technologies and are similar to those successfully flown on the Mars Pathfinder mission. The rotating mass of these pumps is 0.5 inch in diameters with a maximum rotating speed of 9000 RPM.

5.13.7.2.3 Accumulator (Leland's comments: 1. Figure 5.13.7.1-1, 2, 3 does not reflect a heat pipe associated with the accumulator. 2. Section 5.13.7.2.3 is out of date and does not describe the accumulator presented at the October 2005 TIM.)

The accumulator is a CO_2 reservoir tank used to set the evaporation temperature for Tracker cooling and account for expansion of the working fluid. The 1 liter cylindrical tanks (one for each loop) are made of 316LN CRES with an 84mm ID and 4mm wall thickness. Each tank is bolted to the corresponding TTCB base plate. A 316L CRES screen is mounted inside the tanks to act as a capillary wick to assure that the liquid CO_2 is drawn to the wall of the tank. Temperature set point control of the two-phase CO_2 loop is achieved by heating and cooling of the accumulator. Heating is performed by wire heaters around the central heat pipe. Cooling (only) is provided by using Peltier elements located at the accumulator mantle. The elements are mounted to a saddle on the tank. Each Peltier has a cooling power of about 5 watts, corresponding with waste heat of about 15 watts. Waste heat is conducted to the TTCS loop via a heat exchanger (Figure 5.13.7.2-3).

5.13.7.2.3 Heat Exchanger

The TTCS heat exchanger is designed to transfer heat between the Evaporator inlet and exit. This minimizes the amount of pre-heating needed to assure that the CO_2 entering the evaporator if at the saturation temperature. The heat exchanger is a two phase to single phase plate type made of stainless steel with 4mm wall thickness. Inside are 36 plates soldered together (Figure 5.13.7.2.3-1).

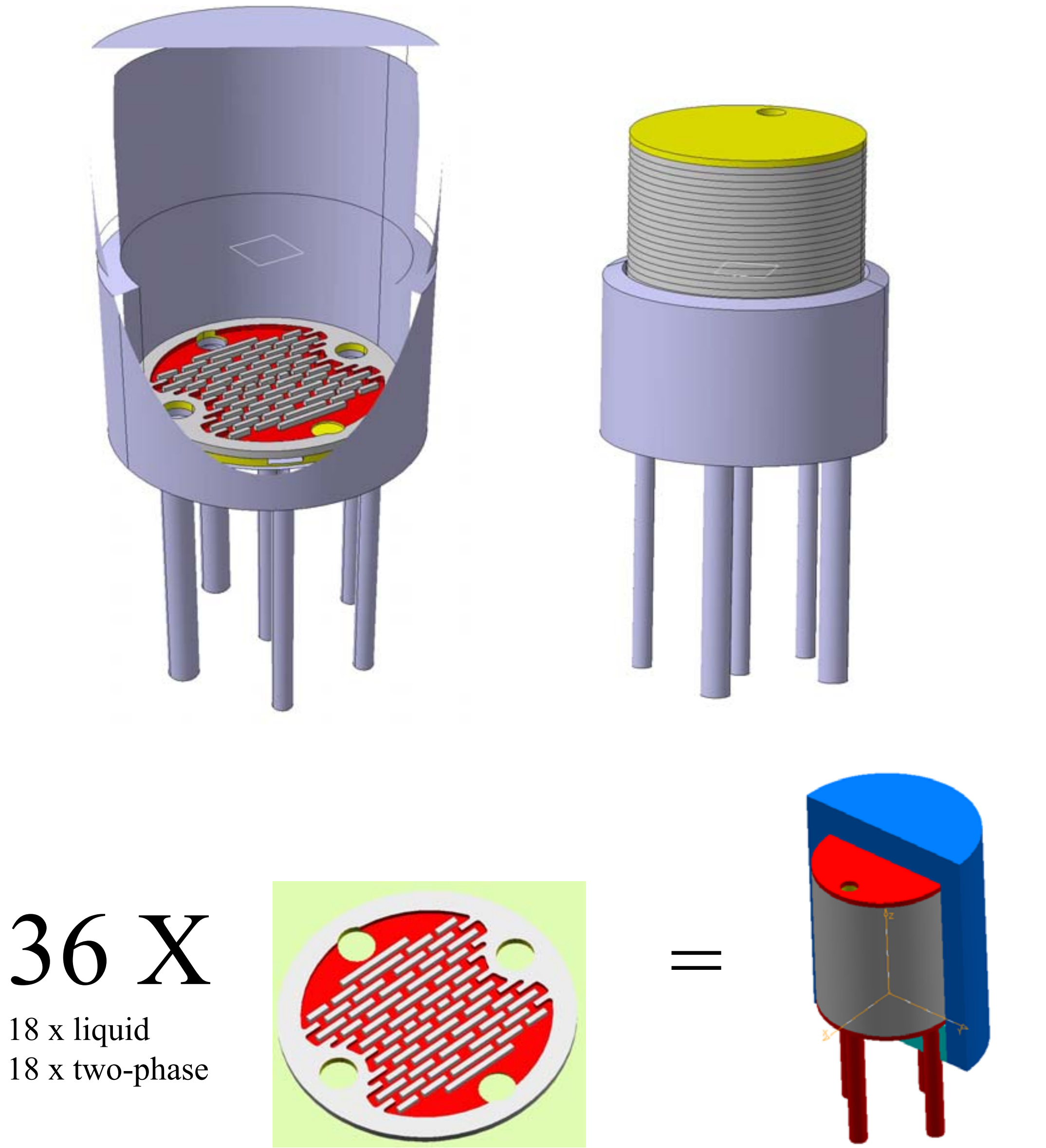


Figure 5.13.7.2.3-1 TTCS Heat Exchanger

5.13.7.2.4 Pre-heaters (Leland's comment: Sections 5.13.7.2.4, 5, need to include heater control circuitry descriptions as well as filling in the one TBD.)

The pre-heaters are used to heat the sub-cooled liquid to the saturation point (i.e. set-point) before it enters the evaporator. Redundant, 8 watt (maximum) heaters (Thermocoax SEA 10/150) are soldered to each of the two evaporator branches (the other two are in the box). The heaters are on/off controlled based on the pump inlet temperature in each branch.

5.13.7.2.5 Cold Orbit Heater

A cold orbit heater similar to the pre-heaters is used to keep the condenser temperature above -40° to avoid freezing of the condensers in cold orbit operation. This 50 watt heater has a simple on/off control based on the pump inlet temperature.

5.13.7.2.6 Start-up heaters (Leland's comment: Sections 5.13.7.2.4, 6, need to include heater control circuitry descriptions as well as filling in the one TBD.)

Start-up heaters are used to heat the liquid CO_2 above -20°C, to avoid overcooling of the Tracker electronics prior to their switch-on. These 50 watt heaters have a simple on/off control based on the pump inlet temperature. The start-up heaters are located on the mantle of the TTCS heat exchanger (Figure 5.13.7.2.6-1).

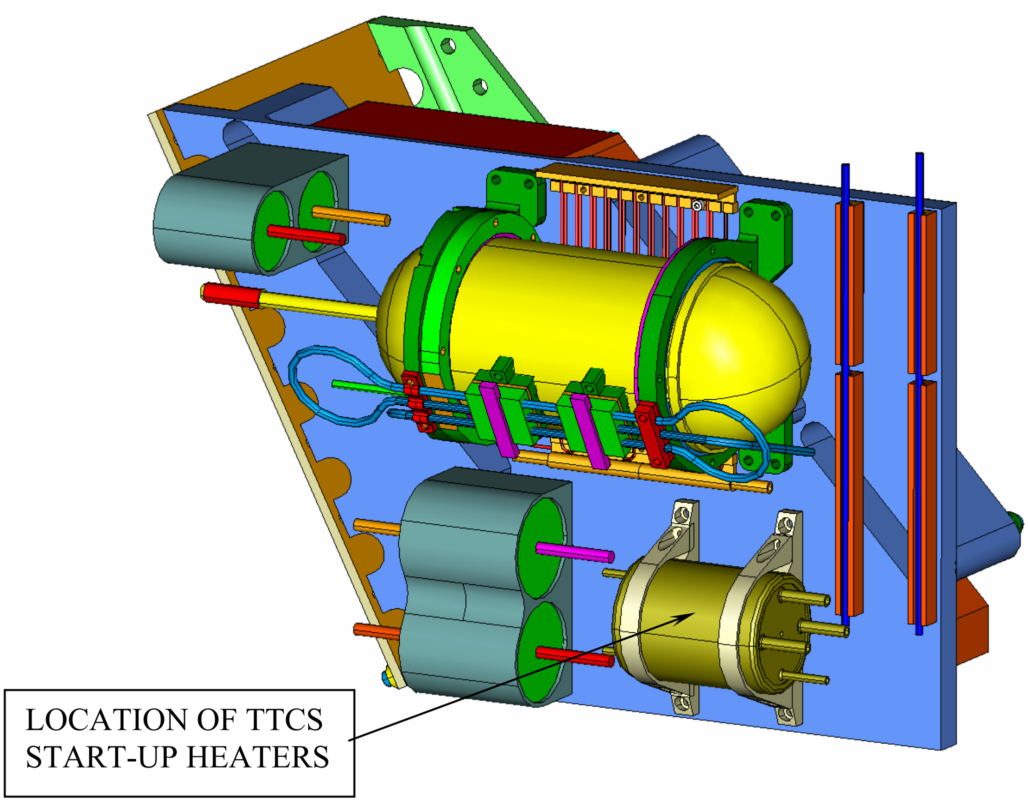


Figure 5.13.7.2.6-1 Start-up Heater Location

5.13.7.2.7 Oscillating Heat Pipe Experiment

The Oscillating Heat Pipe (OHP) experiment is a small, non-intrusive piggy back experiment located in the TTCB. The OHP is a single undulating capillary tube partially filled with liquid slugs and vapor plugs (Figure 5.13.7.2.7-1). Oscillation is achieved by pressure pulses due to evaporation of the liquid on the hot side; however, heat transport is achieved mainly by the sensible heat of the liquid slugs moving back and forth. The principle of this operation is poorly understood, which is a primary driver for this experiment.

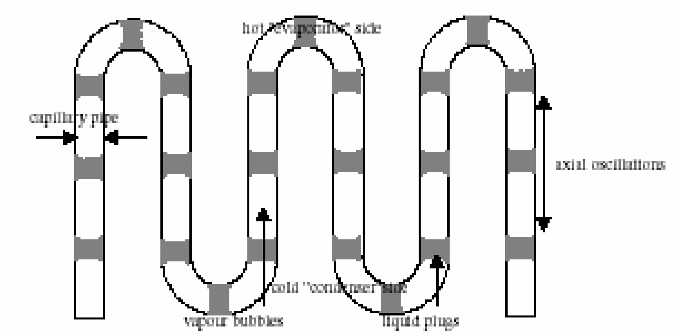


Figure 5.13.7.2.7-1 Oscillating Heat Pipe

Figure 5.13.7.2.7-2 shows the configuration of the OHP experiment. A stainless steel pipe is routed as shown on a base plate. The ends of this pipe are pinched and welded after being filled with the working fluid, 3M FC-87. The "cold" side of the OHP is connected to the CO_2 loop just before the Heat exchanger inlet. A temperature gradient will be imposed using a 50 watt heater (Minco foil K5229 type 1) mounted on the "hot" side. This experiment will only be operated during cold environments.

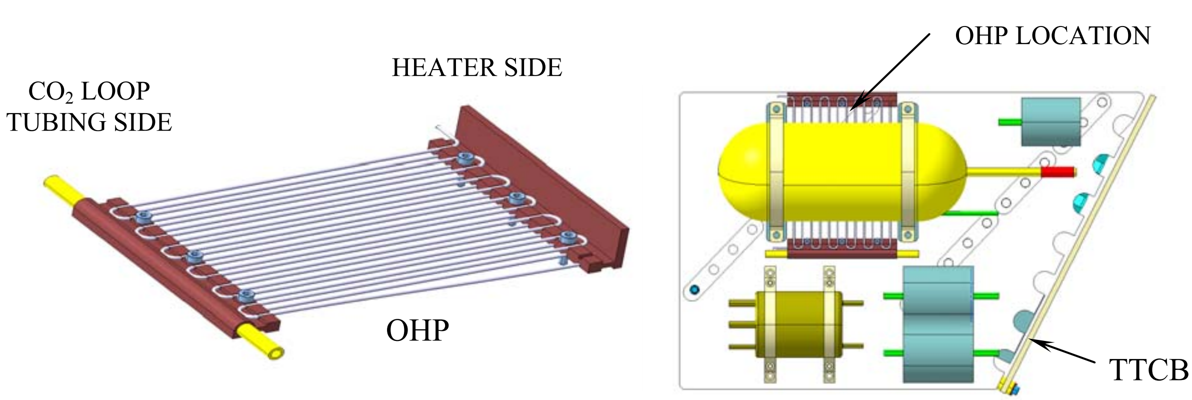


Figure 5.13.7.2.7-2 Oscillating Heat Pipe Experiment

5.13.7.3 CO_2 Freezing/Thawing **(Leland's comment: On Freezing of TTCS will need to be updated with all the new freezing information for additional lines and fittings including the appropriate reference for the open sentence that ends the section.)**

The TTCS is designed to reject heat generated in the Tracker as efficiently as possible. A results of this efficient design, is that when AMS experiences a loss of power the Tracker Radiators will drop in temperature rapidly. Subsequently, the TTCS condensers will also cool down to the environmental sink temperatures. In cold ISS attitudes, temperatures could drop below the freezing point of CO_2 (approximately -55ºC based on fill quantity and pressure) and frozen CO_2 could accumulate in the condenser capillary tubes. By design, the condenser manifolds are mounted in a location (under MLI on the Vacuum case conical flange) which will never freeze. Line heaters on the capillary tubes are design to thaw the CO_2 from the manifold to the condenser after power is restored. The capillary tubes are made of extremely high strength Inconel 718 which is capably of withstanding the pressures due to uncontrolled heating of a plugged section of frozen CO_2. To measure these pressures and verify this design, testing was performed using lower strength stainless steel tubing. This test successfully measured pressures due to freezing/thawing of a plugged section (by measuring induced strain in the tubing) and showed no sign of tube failure. A more detailed description of this test can be found in the test report (NLR Memorandum AMSTR-NLR-TN-039-Issue 03, TTCS Condenser Freezing Test Report).

5.13.8 CAB Thermal Control

(Leland's comment: It has been indicated that the CAB cooling has altered substantially since this was written. This section needs to be updated and the hazard reports as well.)

The Cryomagnet Avionics Box (CAB) is used to monitor and control the AMS-02 Cryomagnet. Power dissipation can vary from as low as 35 watts to over 800 watts during magnet charging. This severe range poses extreme challenges to the CAB thermal design. The CAB itself is design to conduct heat from internal electronics to the box walls. Two Loop Heat Pipes (LHPs) will be used to transport heat from the baseplate (-X side) to the Wake Main Radiator (Figures 5.13.8-1 and 5.13.8-2). During magnet charging, most other AMS-02 electronics are turned off, so this radiator has excess capacity to reject heat. A bypass valve on each LHP will be used to bypass the radiator if CAB temperatures approach low temperature limits. The LHP and bypass design is identical to those used for the Cryocoolers (see Section 5.13.6), except that ammonia will be used as the working fluid and the bypass valve temperature setting will be based on CAB limits.

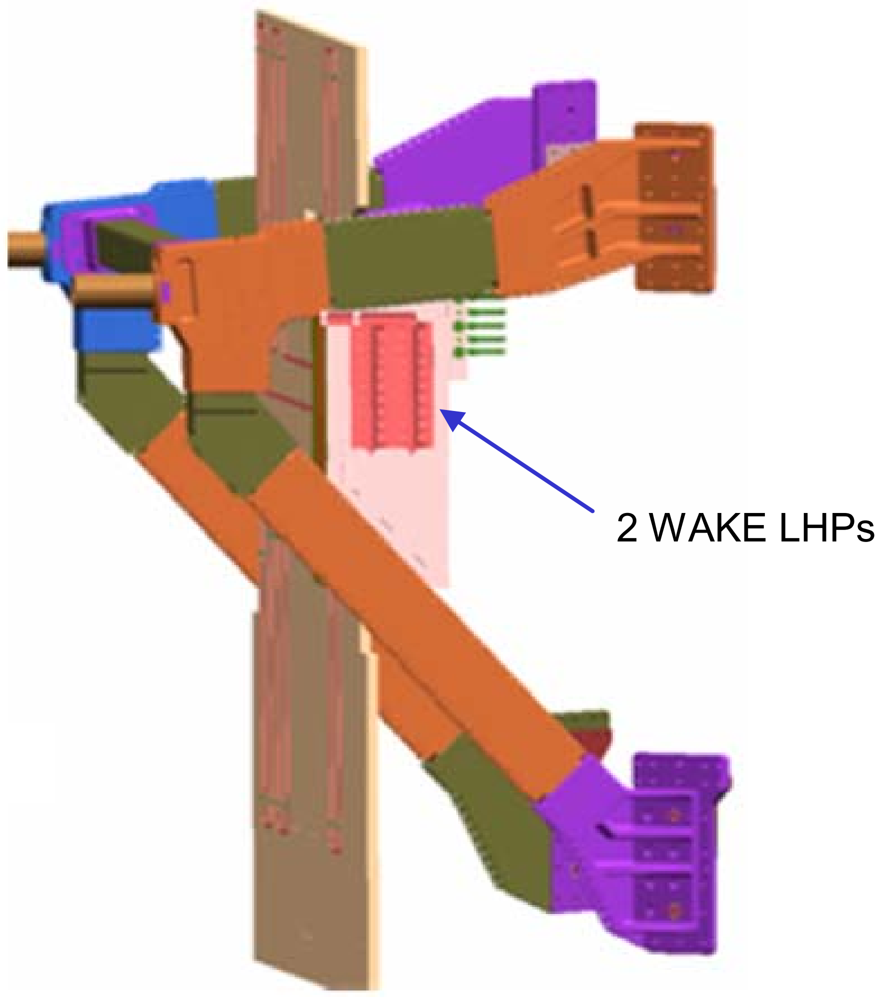


Figure 5.13.8-1 CAB Cooling System

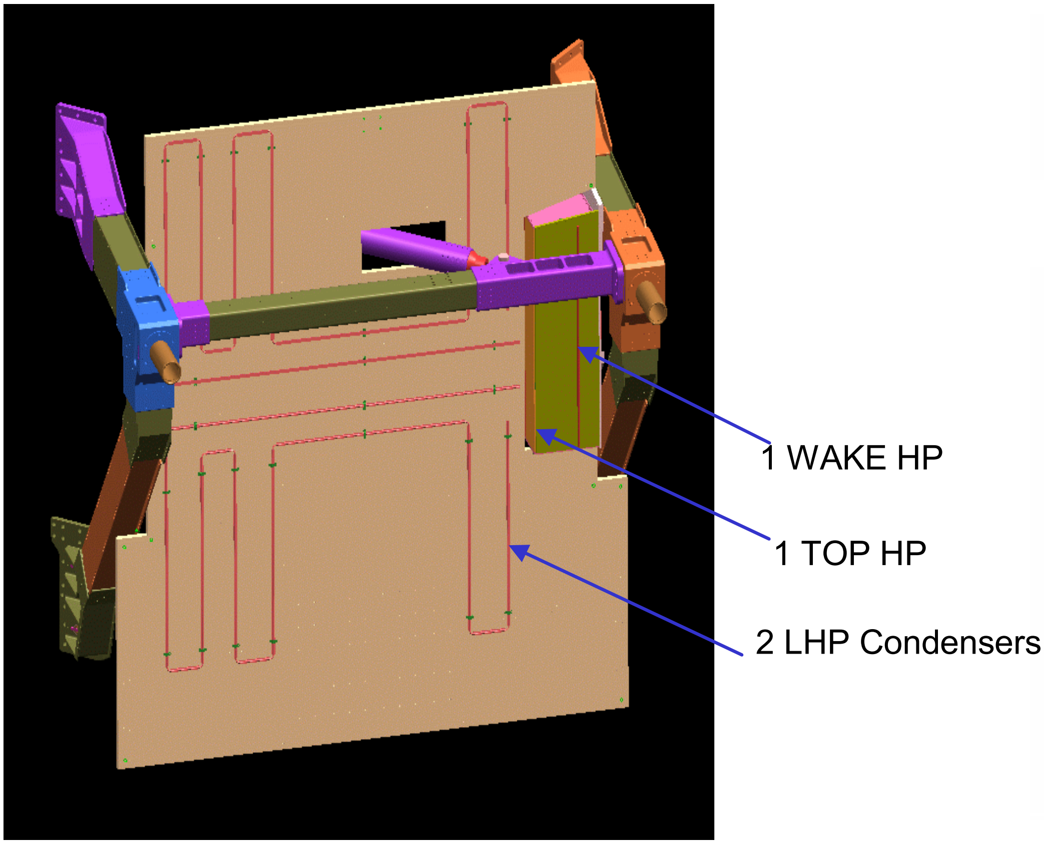


Figure 5.13.8-2 CAB LHP routing on Wake radiator

Additional axial groove heat pipes will be mounted to the base plate and top (+Y side) to help distribute heat. Heat pipes are also mounted between the USS-02 Upper Trunnion Bridge Beam and the Upper Vacuum Case Interface Joint (Figure 5.13.8-3). This is needed to help the CAB reject heat during Magnet charging. The outer surface of the CAB is covered with silver Teflon to bias it cold. Heaters will be used to maintain the CAB above minimum temperature limits.

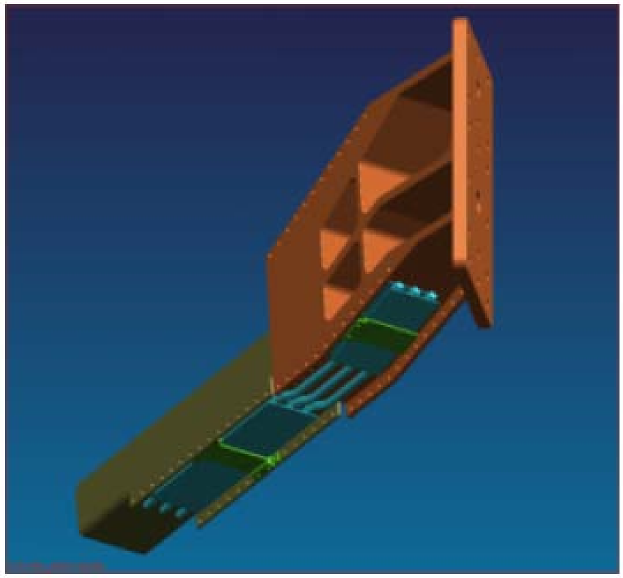


Figure 5.13.8-3 Heat Pipes on USS-02

5.13.9 TRD Thermal Control

The Transition Radiation Detector (TRD) has some of the most severe thermal requirements on all of AMS (Figure 5.13.9-1). In addition to component temperature limits, the entire detector needs to be isothermal within +/- 1ºC. To achieve this goal the 4 main structural interfaces to the USS-02 are isolated as much as possible with titanium spacers and the Zenith Radiators are each mounted to the top of the TRD with 14 fiberglass-epoxy pins, design to minimize heat leak. Cable and plumbing feed-throughs are also kept at a minimum and insulated to reduce heat leak. The entire detector, along with the Upper Time-of-Flight (UTOF) is completely enclosed in a 20-layer MLI blanket (Figure 5.13.9-2). Small TBD watt heaters **(Leland's comment: Section 5.13.9 has TBD in it.)** are glued to the M-structure to minimize gradients and keep the entire detector within the desired temperature range.

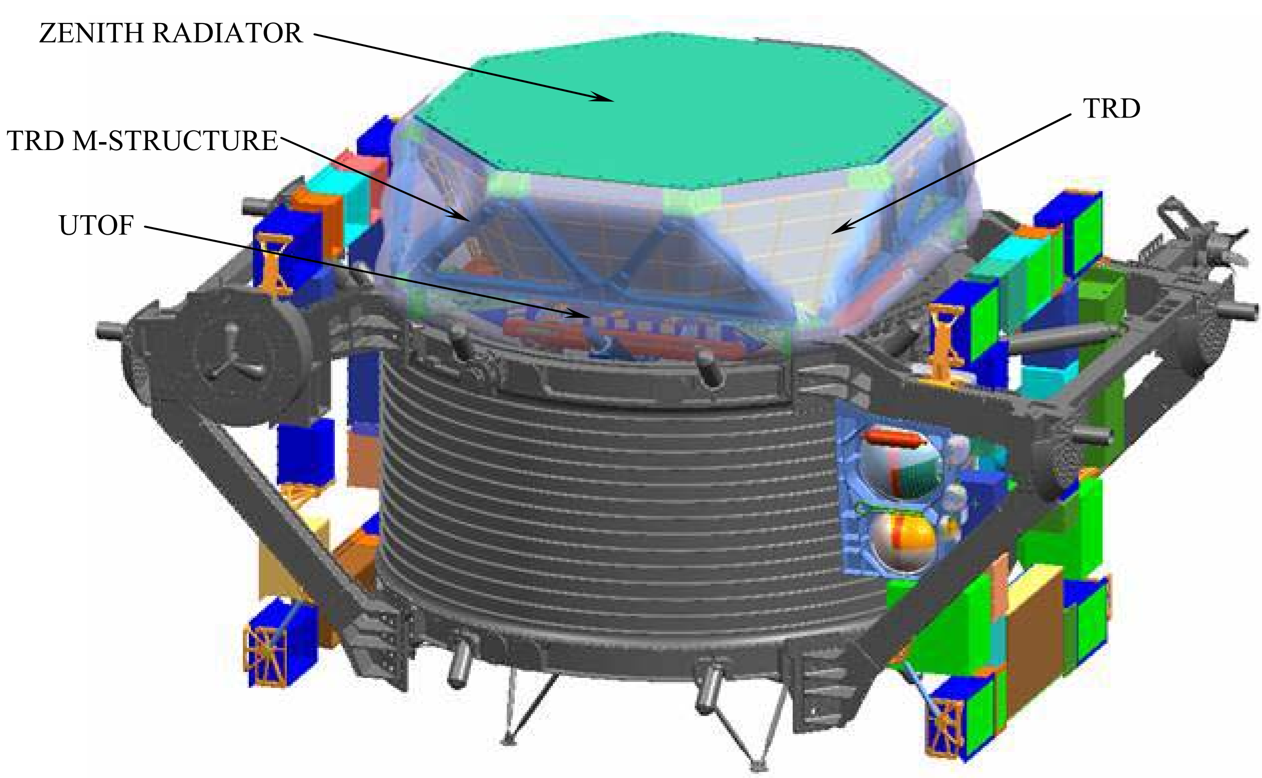


Figure 5.13.9-1 TRD on AMS-02

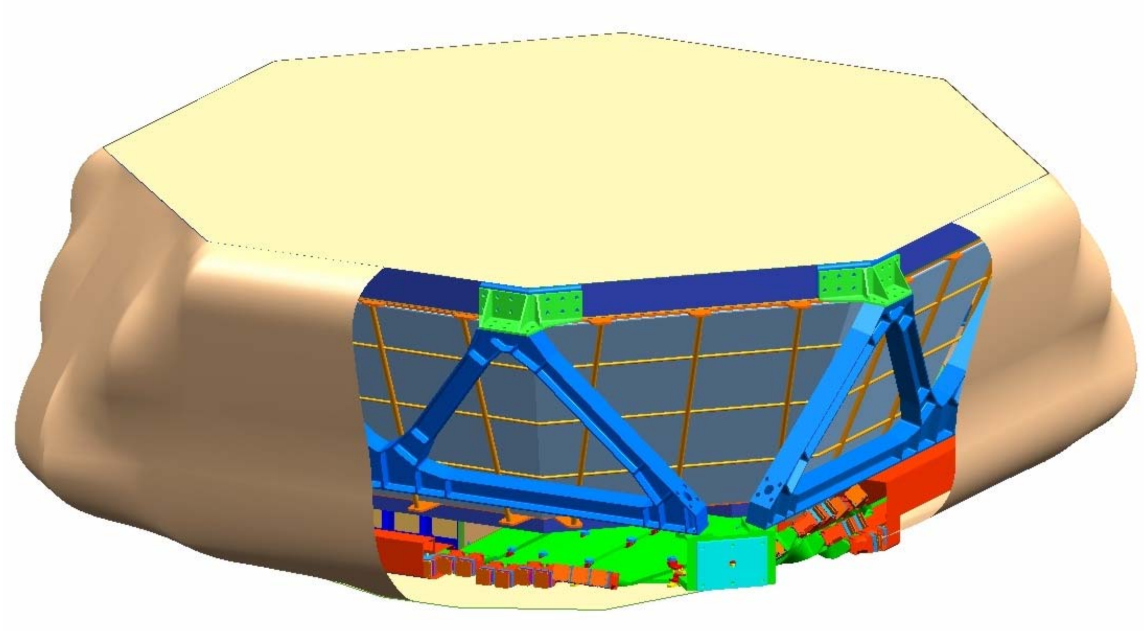


Figure 5.13.9-2 TRD MLI

5.13.10 TRD Gas Supply Thermal Control

(Leland's comment: Section 5.13.10 has to be updated to reflect latest information that was presented at the TIM on the number, size and locations of heaters.)

The TRD Gas Supply system S-box (Figure 5.13.10-1) provides a mixture of Xenon and CO_2 to the TRD. Active heating is required to keep both the Xenon and CO_2 tanks above their respective saturation temperatures. This is needed in order to monitor the amount of fluid remaining in each tank by means of a pressure sensor. Due to an extremely long time constant, it is not possible to quickly warm up the fluid in the tank. The Xenon must be maintained above 25ºC (TBC) and CO_2 above 33ºC (TBC). Kapton foil heaters are glued to the surface of the Composite over-wrapped stainless steel tanks. Two strings of eight heaters patches (one for each power feed) are distributed around the tank surface. Three thermostats in series (one on the return leg) are implemented to avoid "run-away" heaters which could cause the maximum design temperature to be exceeded. Engineering evaluations in thermal-vacuum were performed to quantify any temperature gradients between thermostats and heaters. Small persistent heaters (resistors) are attached to the exposed metal bosses will be powered continuously to minimize heat leak to the base plate. Each individual tank is wrapped in multi-layer insulation (MLI) and the entire TRD Gas Supply S-box in another MLI blanket.

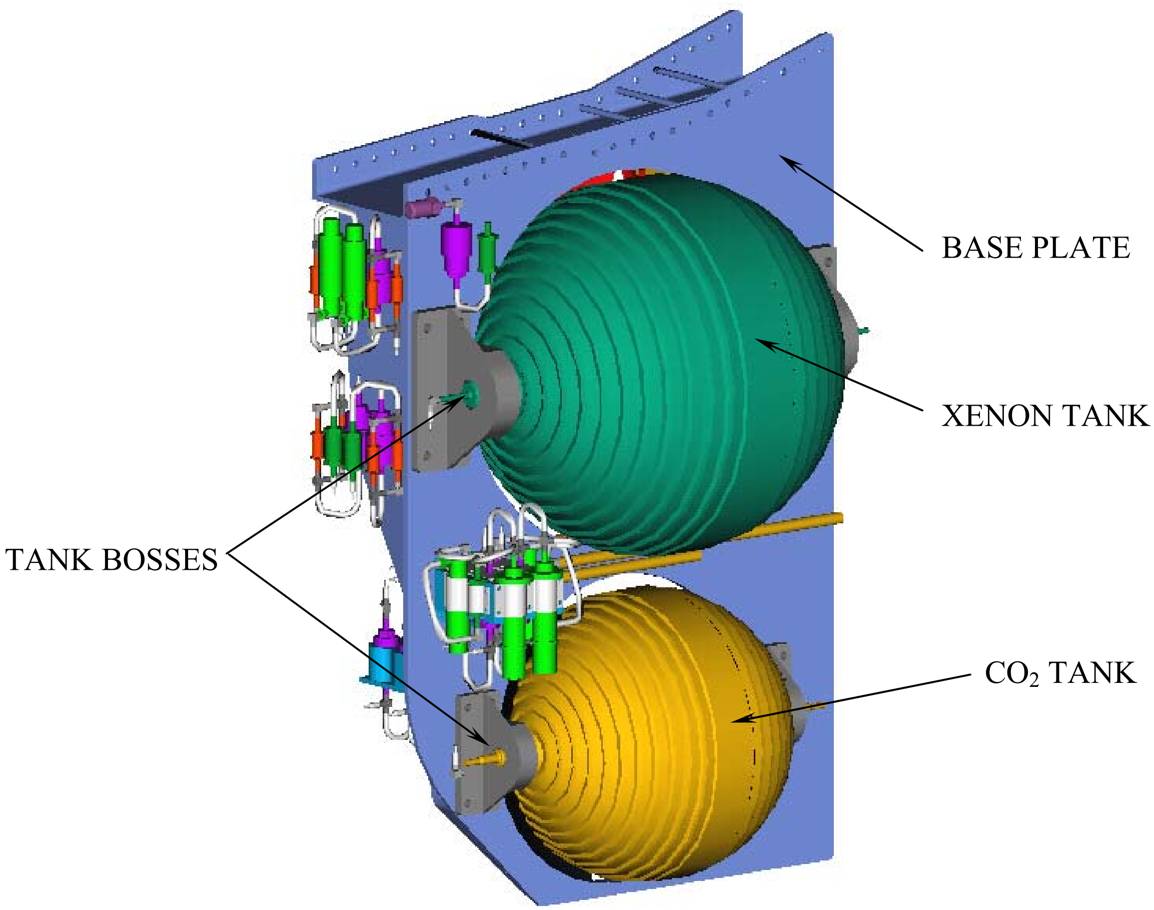


Figure 5.13.10-1 TRD Gas Supply (Box S)

5.13.11 AMS-02 Thermal Analysis

Extensive thermal modeling and analysis has been and will continue to be performed on the AMS-02 Payload. To date most analyses have been focused on design, but this will soon shift to verification.

5.13.11.1 AMS-02 Thermal Models

Detailed thermal models have been developed for all AMS-02 hardware. An integrated AMS-02 Payload model has also been integrated with both the ISS (Assembly Complete) and STS (390 Node Model). For some experiment components, a reduced model is used for integrated analysis. Detailed analysis is performed with a stand-alone model using interface data from the integrated analysis. Iterations are performed to confirm that the reduced model adequately represents the interfaces used in the detailed analyses.